II, it is certain that only 1 fish moved there from station I. One other fish moved to station III from either station II or station I. Apparently, movement was not extensive at any time and particularly after November 22.

Little information is available concerning the movements of coral reef fishes. After a number of tagging experiments, Randall (1955) concluded that extensive migrations of the surgeon fish, *Acanthurus triostegus sandvicensis*, do not take place, and Helfrich (1958) noted that *Abudefduf abdominalis* tagged along the south edge of Coconut Island remained in the vicinity for a period of about four weeks after which they lost their tags or migrated to other areas. Bardach (1958) tagged a number of reef fishes in Bermuda and observed that two out of five specimens of the pomacentrid fish, *Abudefduf saxatalis* (Linnaeus) remained at the same small reef on which they were tagged for 30 and 50 days, while *Pomacentrus fuscus* and *Pomacentrus leucosticus* were observed in the same locality for over 40 days.

2.9 COLORATION

Because of their more accessible location in shallow water, juveniles are more often seen than adults. In such locations, they are usually well pigmented and show a maximum of contrast between the dark and light areas of the body. They also have a conspicuous spot that may be either white or turquoise. However, under certain conditions, juveniles become very pale in appearance although not to the same extent as the adult.

The coloration of adults ranges from an almost pure white (except for caudal, anal and ventral fins) to an almost pure black condition with intermediate shades of gray. The particular coloration of an individual is closely related to its behavior and therefore, is discussed as a function of that behavior. Three types of coloration are recognized in relation to the state of activity of the fish -- nuptial, feeding and excitation. The first has already been discussed (Section 2.4.1) but will be compared with the other two in the following sections.

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2.9.1 Feeding Coloration

Adult as well as juvenile *Dascyllus albisella* spend almost all of their time feeding. The only time when fish do not feed is when they are engaged in reproductive activity and when they are within the coral head. Since most of the time is spent feeding, the general coloration of the fish is called "feeding coloration" in this work. Although fish in Kaneohe Bay spend most of their time feeding, their behavior is such that the general coloration might result from the influence of other stimuli in the environment (Section 2.7.1).

The colors of feeding fish vary from jet black to almost pure white depending on the age of the fish, the composition of the bottom over which they are feeding, and their state of excitation. Juveniles living under indentical conditions, except for the type of bottom around the coral head, are darker in color over rock bottom than over sand bottom. Figures 10 and 11 (taken at a depth of 70 feet off Waikiki) show two aggregations of juveniles on the same day under conditions as described above. The darker fish over the rock bottom (Figure 10) show only a suggestion of gray surrounding the white spot on the body and on the snout. The fish over the sand (Figure 11) are very pale except for two vertical gray-black stripes.

It is suspected that the reflection of light from the bottom is not the only factor influencing the coloration. Juvenile fish over rocky bottom behave differently from those over sandy bottom. The former stay much closer to the coral head and only make occasional short dashes outward after food. The latter, however, extend much farther out and do not dash back into the head as readily as the former, although they may return part way when frightened. It is quite apparent that the fish over the rock bottom are more active than those over sand. As will be seen shortly, adult fish show a darker coloration under the influence of increased activity. The basis for the increased activity

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Figure 10. Dark feeding colors of juvenile Dascyllus albisella associated with an experimental Pocillopora meandrina coral head located on rock bottom off Waikiki Beach.

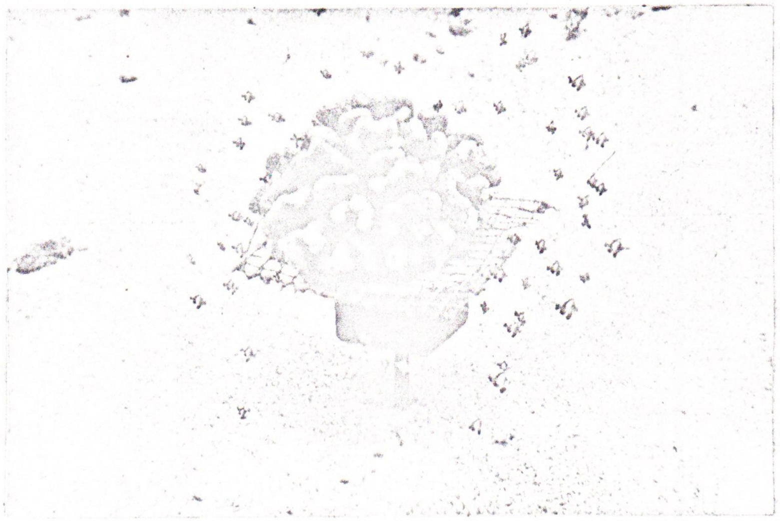

Figure 11. Light feeding colors of juvenile Dascyllus albisella associated with an experimental Pocillopora meandrina coral head located on sand bottom off Waikiki Beach.

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of fish over hard bottom is believed to be an interaction between factors such as water movement (in some areas), the presence of other fish (including predators) and possibly sign stimuli presented by surrounding physical features.

The coloration of adult *Dascyllus albisella* in Kaneohe Bay is different from that of adults found off Waikiki. In the former area, the fish are black with the white body spot showing very distinctly. However, off Waikiki, the fish are almost entirely white, except for caudal, anal and pelvic fins. The whiteness, however, is slightly dulled by a faint pigmentation on the borders of the scales. This coloration is almost identical to the nuptial coloration of reproducing fish and appears to differ only in the presence of the pigmentation on the borders on the scales and possibly in the lack of an orange tint in the caudal fin. It must be emphasized, however, that these differences are subjective impressions, and no difference actually may exist. The only sure way to differentiate between a fish in nuptial colors and a feeding fish is to study its behavior and its location in respect to the bottom. Figure 12, which shows a guarding male *Dascyllus albisella* in nuptial colors, may be compared with Figure 13 which shows the feeding colors of an aggregation of adult *Dascyllus albisella*.

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Figure 12. Male Dascyllus albisella in nuptial colors over nest site.

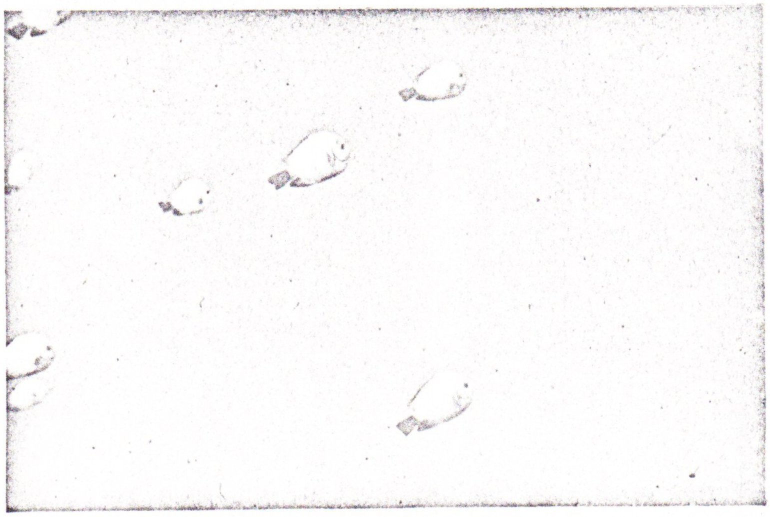

Figure 13. Part of an aggregation of adult Dascyllus albisella showing feeding coloration.

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2.9.2 Excitation Coloration

Fish that are in a state of agitation or excitation show a different coloration from those already mentioned. The head and anterior part of the body posterior to the pectoral fin turn a dark gray-black as does the dorsal fin, and the caudal peduncle. The remainder of the body becomes a light shade of gray and the white spot high on the body is often conspicuous. Figure 14, taken at a depth of 70 feet off Waikiki, shows this type of coloration which here is displayed in the presence of the diver, who has stirred up the bottom.

This coloration becomes prominent within a matter of minutes when fish become excited. Male fish that are engaged in nesting change from the white to the dark condition if they are continually disturbed. The intensity of the contrast depends on the duration of disturbance. If sea urchins are crushed near the fish, or a disturbance is made on the bottom which they come to investigate, they also make the transition from the white to the dark coloration.

The fish become quite active before the actual color change occurs. Nesting fish often grunt loudly and dart quickly around a human observer disturbing the nest site. Fish that gather at some disturbance on the bottom mill around excitedly and make short dashes at particles that

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Figure 14. Adult *Dascyllus albisella* showing excitation colors in response to the activity of the diver.

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are stirred up. After the cessation of such activity, the color gradually fades and the fish "settle down" and move quite slowly again.

It is thought that the reason for the dark coloration of the fish in Kaneohe Bay is related to their more active state. They appear to be relatively timid and cannot be approached closely by an observer. They spend their time close to the coral and make more darting movements than Waikiki fish. They approach a stationary observer with the greatest caution and with many quick advancing and fleeing motions. They show a high state of activity similar to that of juveniles that are associated with coral heads.

The similarity in color between the feeding fish at Waikiki and those on the nesting site is believed to result, partly at least, from a relative state of inactivity. The fish guarding the nests spend most of the time hovering quietly in the water. Attacks upon other fish are rather infrequent and are of very short duration. They engage in the nuptial display only infrequently. However, as the nest becomes older, the guarding male becomes darker. This can be related to the extent of excitation for the fish spends more time fanning the eggs and chasing away other fish with more prolonged attacks.

Feeding adult fish, in contrast to juveniles, move

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very slowly. They maintain their positions in the water by using the pectoral fins only. The trunk musculature is apparently used for other activities, such as reproduction and rapid movement in escaping from enemies. The general appearance of a feeding aggregation is one of unhurried activity in which fish seem to be suspended in the water and pick out the plankters that drift past. The energy expenditure of the fish is obviously not great.

The significance of color and color changes in fishes has received wide attention in the literature. In many teleosts, the color changes so as to blend with that of the background. Variation in this phenomenon ranges from species like Carassius and Pomacanthus, which show no grossly evident response to the background (Breder, 1959), to species of flounders which may change the pattern as well as the color to match the surroundings (Mast, 1916). Within the flatfish family Pleuronectidae, the color may vary from extremes of gray and black to shades of blue, green, orange, pink or brown. Coloration and color changes in cyclostome, elasmobranch and teleost fishes as well as a discussion of the role of chromatophores has been the subject of an extensive review by Parker (1948).

The basic color assumed by fishes in relation to their background is strongly influenced by particular drives. Breder (1959) pointed out that "colors in response to an

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emotional state act more or less independently of and may interfere with the full expression of colors that match the background and in some cases may fully suppress them." Such phenomena have been most often studied in relation to courtship coloration where male fish often assume vivid hues that make the fish contrast more or less strongly with the background rather than blending with it. This type of adornment is particularly marked in male fish of species that show territoriality and guard the eggs (Noble, 1938). Earlier opinions as to the attractiveness of such colors to females of the species, were confirmed and some of the properties of the particular colors and behavior involved in the response were elaborated by Pelkwijk and Tinbergen (1937) in their classical experiments with models of the three-spined stickleback, *Gasterosteus aculeatus* Linnaeus. Their findings revealed that to evoke courtship in a female, the model must have a red patch on the underside, a greenish-blue upper side and a blue eye. On the other hand, courting by the male occurred in the presence of a model which was silvery colored and had a swollen abdomen. Baerends and Baerends-van Roon (1950) showed that in some species of cichlid fishes (e.g., *Hemichromis bimaculatus* Gill), the young followed the parents in response to a combination of typical movements and color. The same authors also present an analysis of changes in the chromatophore systems that produce color changes in the cichlid fishes.

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The high state of excitement shown by fish during reproductive activity as well as fighting is accompanied by brighter hues. The basis for such a correlation no doubt lies in the interaction of nervous and hormonal elements that generally combine to produce color changes (Parker, 1948; Baerends and Baerends-van Roon, 1950; Breder, 1959). Like male *Dascyllus albisella*, which becomes darker when fertilizing eggs, the color of *Abudefduf abdominalis* rapidly intensifies during certain maneuvers associated with reproductive activity (Helfrich, 1958); similarly, *Dascyllus trimaculatus* briefly changes to a pale blue color (Garnaud, 1957). It is not unreasonable to expect that a generally higher level of activity in *Dascyllus albisella* in relation to stimuli other than that produced by reproductive activity would result in fish assuming (darker) coloration. It is likely that coloration changes resulting from fright and curiosity also occur in other fishes, although such changes could be expected to be specific to different species.

The author has observed that *Dascyllus albisella* and also *Dascyllus trimaculatus* assume a light coloration when they are inactive in aquaria at night. This is probably typical of pomacentrids as it has also been observed by Breder (1949) in *Pomacentrus leucostictus* and *Abudefduf saxatalis*, and by Franzisket (1959) in *Dascyllus aruanus*. These observations are in accord with the hypothesis that in *Dascyllus albisella* lighter color is associated with lesser activity and *vice versa*, although the intensity of light itself is doubtless involved.

Coloration of fishes in relation to background has been given considerable attention by Breder (1948, 1949, 1959), who points out that one of the most obvious and widespread reactions of fishes is their tendency to match the tone and often the color of the background against which they are seen. However, fish usually keep dark colors unless the bottom within the visible range is light sand. He also stated that changes in locomotion, color and pattern, which are both hormonally and nervously controlled, are generally the first responses of a teleost to a given stimulus. The behavior of at least some fishes appears to be related in some way to changes in background coloration since Breder (1959) showed that lighter colored clupeoids would only swim over a matching background and avoided darker backgrounds that contrasted with their coloration. The author has also seen pale goatfishes avoid darker patches of reef even when pursued vigorously.

In contrast to the above observations, some fishes assume a maximum contrast rather than a blending with the background. This was the case with juvenile *Chaetodipterus fabre* (Breder and Rasquin, 1955), which assume a dark coloration, thus resembling conspicuous particles of inanimate objects over sandy bottoms. Randall (1960), in a study of mimicry and protective resemblances in marine fishes, pointed out a number of species of different families that contrast with the general background while matching such floating materials as sticks, leaves, and algae. The great diversity in coloration of fishes in relation to background points out the complex nature of the nervous-endocrine mechanisms involved.

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SECTION III

ECOLOGY OF JUVENILES

Ecological studies of the interrelationships between coral reef fish and the physical and biological factors in their environment are relatively few in number. Most of the literature deals with a few specialized ecological aspects involving such conditions as commensal relationships between fish and anemones as reported by Garnaud (1951), Gohar (1934), Gudger (1929), and Verwey (1930). The increased interest in the productivity of marine environments in recent years has given considerable impetus to ecological studies, but the invertebrate organisms and primary producers have received the bulk of the attention (Odum and Odum, 1955). Predator-prey relationships among marine animals remain obscure particularly from the point of view of field observations. Most field work that deals with the interactions between populations of animals has been carried out by observing insects (Brian, 1952; De Bach, 1949; Elton, 1949). Information concerning the coral reef fishes and their environment is widely scattered throughout the literature and usually exists as brief notes concerning some occurrence that has not been integrated with other pertinent facts in the animal's ecology.

However, a few works dealing with the biotic and physical interactions between species of coral reef fishes are available. Among these are the works of Helfrich (1958) and Randall (1955), which dealt with the life histories of *Abudefduf abdominalis* and *Acanthurus triostegus sandvicensis* respectively. Among other things, these works deal with the early life histories of juveniles in their most characteristic habitat, the tide pool. The effects of surge, temperature and predation were considered in these habitats, but little attention was given to these factors in the areas where juveniles were not present. As a result, it is not possible to make a comparison between habitats that might indicate which factors are influential in determining distribution. Hiatt and Strasburg (1960) gave what is probably the most comprehensive account available of the ecological relationships between fauna on coral reefs. They dealt mainly with food and feeding interrelationships as well as with the general aspects of distribution in relation to substrate and hydrographic features. Gosline and Brock (1960) gave a brief account of the types of fishes found on coral reefs under varying conditions of water movement and types of shelter.

The present study was suggested by a number of questions that arose from observations on the habitat of juvenile *Dascyllus albisella*. The tendency for juveniles of this species to congregate around living coral of the genus *Pocillopora* is widely recognized throughout the islands.

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However, they are also fairly often found in sizable numbers around pilings, sea walls, and other species of coral as well as in less numbers around sponges, poisonous sea urchins and large sea anemones. Therefore, it was apparent that a study of the fish in relation to such seemingly diverse habitats was essential to a life history study.

The scarcity of young Dascyllus albisella in the presence of surge led to the suspicion that this environmental factor was very important in determining their distribution. Gosline and Brock (1960) as well as Hiatt and Strasburg (1960) also recognized the possibility that this factor was important to the distribution of different coral reef fishes. Therefore, the investigation of this specific component of the environment was singled out for particular emphasis in this study.

In addition to providing details of the life history of one of the little known coral fishes, the present study was envisioned as having more far-reaching application. Any knowledge that can be gained in connection with the ecology of marine fishes is much needed as a basis for future studies of both the ecological interrelationships of marine animals and their behavior. According to Andrewartha (1961) ". . . we must first discover the laws governing the distribution and abundance of animals before we can advance very far in our understanding of the relationships between the populations that make up a community."

The study embraced portions of two of the "three levels of complexity" in the laws of ecology referred to by Andrewartha (1961). The first of these, and apparently the least complex, are the "laws governing the physiology and behavior of individuals in relation to their environments." The second are the "laws governing the numbers of animals in relation to the areas that they inhabit: this is sometimes called population ecology." The third level of complexity, "the laws governing communities, which may be thought of as groups of interacting populations", is dealt with only lightly. The study was also expected to contribute toward an understanding of the dynamics of the ecosystem as a whole, which Clarke (1954) referred to as "the operation of the community and its environment as a functional unit." However, the present work does not deal with the complete ecosystem since certain biotic factors, e.g., surgeon fishes and wrasse fishes, were not studied because they were not considered important to the survival of juvenile Dascyllus albisella.

The basic criterion involved in much of this study was the distribution of young Dascyllus albisella in relation to their abundance. The commonness or rareness of the fish was a relative, rather than an absolute consideration. For example, it became clear that the fish were relatively scarce in the presence of strong surge and large numbers of predators, and they were relatively abundant in calm water where predators were lacking and in coral heads of a particular type. The investigation probably most closely approaches that which Macfadyen (1957) would call a "field level" of investigation, which in this case also included experiments in the field. Attempts to carry out studies in the laboratory at the "experimental level" of investigation were largely unsuccessful.

It is very difficult to present simply the results of an analysis of various environmental factors as they occur in the field. Since the factors influence each other in various known and unknown ways, it is almost impossible to refer to one without considering its relationship to the others. For this reason it has been necessary to make cross references when discussing a particular environmental factor. In this dissertation, the factors are dealt with as separate units but are discussed in relation to each other and to the areas and sections in which they occur.

3.1 FEATURES OF STUDY AREAS

Four areas were selected for the study of the fish in relation to their environment. The Waimanalo, Kaneohe Bay and Kualua areas were selected because they contained the largest populations of juvenile fish that were found (see

Figure 15). The Waikiki area was selected because it offered an area of quiet water that presumably should be, but actually was not, inhabited by very large numbers of juvenile fish. All the areas, except Kaneohe Bay, had sections in which fish were concentrated alongside of sections in which fish were scarce. Different hydrographic and geographic conditions occurred in the areas with and without fish, thus affording a possible basis for the differences in numbers of fish.

3.1.1 Waimanalo Area

The area is located about three miles southeast of the town of Waimanalo (see Figure 15). The portion of reef studied was divided into four sections in such a way as to take the fullest advantage of natural geographic features as boundaries.

3.1.1.1 Section A

This section is a shallow flat ranging in depth from about three to five feet. The bottom is composed of basalt rock encrusted with various marine animals and algae, and from which isolated coral heads jut to heights of from six to twelve inches from the bottom. A few crevices of not more than a foot in depth and a few low mounds produce a slightly uneven bottom. The southern boundary is clearly defined by a sharp upward slope about 100 feet from shore. The slope is the outer boundary of a shallow flat adjacent

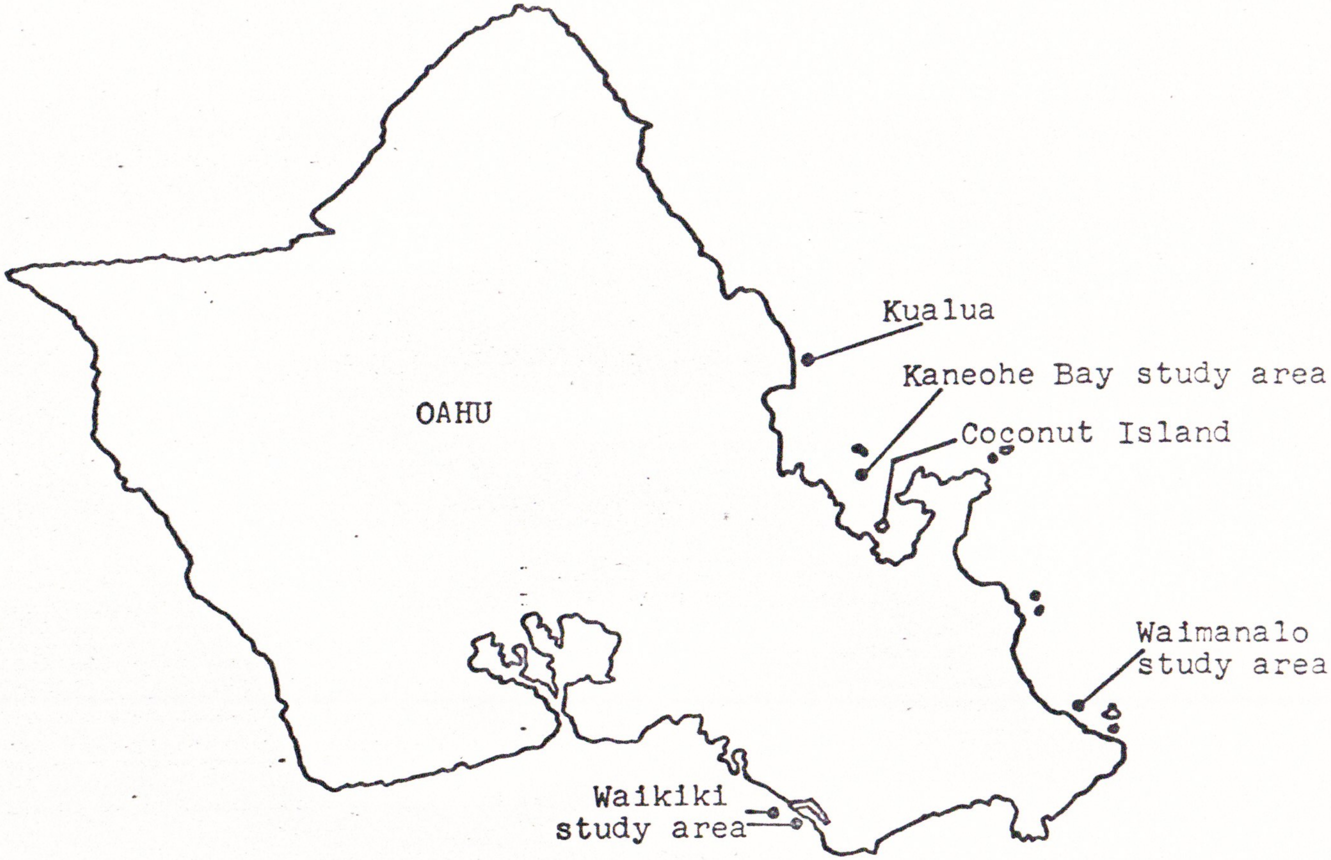

Figure 15. Map of Oahu showing study areas.

to the shore, which is exposed at low tide. The western boundary, due to the lack of natural geographic features, is an imaginary line fixed by range markers located on the shore. The eastern boundary is also a range line since the bottom continues in that direction where it terminates at the edge of section D. The northern boundary terminates at the edge of section C, which is a well defined channel with steeply sloping sides. The total area encompassed by section A is about 10,000 square feet.

3.1.1.2 Section B

This section is much like section A except that the depth is shallower, ranging from about 2 to 4 feet in the central, northern and western portions. The southern portion is a gradual slope from the shallower central portion down to the edge of section C, where the depth is about 8 feet. The northern boundary is marked by a fairly abrupt slope which drops down to another channel, the bottom of which lies about 5 feet below the surface. The eastern and western boundaries, as in section A, are bounded by imaginary lines that are accurately located by ranges. Coral heads are somewhat more scarce than in section A and the relative numbers of the two dominant species is slightly different (see Table 9). The area encompassed is smaller than section A, being about 7500 square feet.

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WAIMANALO	TOTAL NUMBER HEADS	PERCENT P. MEANDRINA	PERCENT P. MEANDRINA INHABITED	PERCENT P. LIGULATA	PERCENT P. LIGULATA INHABITED
Section A	32	22	8	78	92
Section B	43	32	21	68	79
Section C	-	0	0	100	100
Section D	-	0	0	100	100
Kaneohe Bay	30	37	50	63	50

TABLE 9. COMPARISON BETWEEN NUMBERS OF CORAL HEADS OBSERVED IN THE FOUR SECTIONS COMPRISING THE WAIMANALO STUDY AREA.

3.1.1.3 Section C

This section is a channel extending in a northeast-southwest direction at a fairly uniform depth of 8 feet, the sides sloping rather abruptly up to section A and much more gradually up to section B. Interspersed sparsely throughout the sandy bottom are boulder-sized glomerate coral heads of the species *Porites pukoensis*. A few isolated coral heads of the coral *Pocillopora ligulata* are irregularly distributed throughout the area. An island in the sand, which is populated by a few coral heads, was chosen as the northeastern boundary and the southwestern boundary terminates at a large head of *Porites pukoensis*. The length of the channel is about 75 feet and the average width about 10 feet enclosing an area of about 750 square feet.

3.1.1.4 Section D

This section is also a channel lying about 100 feet south of section A and running in an almost north-south direction. At the shallower inshore end marked by an island in the sand, the channel is about 50 feet across. It gradually narrows in a seaward direction and then opens out again to a width of about 40 feet. The seaward terminus was taken as a fairly large island that rises some 6 or 7 feet from the bottom. Except for the narrowest portion, the western edge slopes gradually back toward sections A and B, while the eastern edge is composed of a nearly vertical rock outcropping that rises some 10 to 12 feet from the bottom. As in section C, there are large glomerate coral heads and small ramose types scattered throughout the sandy bottom, which varies in depth from about 10 to 15 feet. The length of the ditch is about 130 feet and the average width is about 20 feet enclosing an area of about 2600 square feet.

3.1.2 Kaneohe Bay Area

The Kaneohe Bay study area presents a different type of habitat that the Waimanalo area. The bottom is flat and is located alongside the western edge of the sampan channel at a depth of about 10 to 12 feet. For the most part, the bottom consists of areas of barren coral rock from which juts an occasional coral head, usually of the species *Pocillopora ligulata* and *Pocillopora meandrina*. Lying between the areas of flat, encrusted rock are areas of sand that range in size from small pockets to areas of 100 or more square feet. In the center of the study area, which measures about half an acre, is an oval-shaped plot of the low growing alga, *Dictyosphaeria* sp. The plot measures about 50 feet in length and contains a number of coral heads of the species *Pocillopora ligulata* that protrude above the surrounding algae. This particular area had a large population of *Dascyllus albisella*, measuring from

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about 30 to 80 mm. in length. No juveniles were associated with the coral heads that were interspersed among the algae. The area is more uniform than the Waimanalo area, which is broken up by a few channels and smaller crevices.

3.1.3 Kualua Area

This area consists of the general reef area between shore and the surf zone off the Kamehameha Highway about one mile northwest from Mokulii (Chinaman's Hat Island). The reef at that point is about one-half mile wide from the shore to the surf zone, which closely approaches the shore about one-half mile north of the general area of observation, but holds well offshore in a southeasterly direction.

The reef itself is shallow ranging in depth from about 2 to 4 feet in the central portions. The bottom is mostly flat with occasional very shallow depressions running through it. The shallower portions lie nearer the shore, the bottom sloping very gently toward the surge zone, where it again rises within about 2 or 3 feet of the surface. Coral heads mostly of the species *Pocillopora ligulata* protrude noticeably above the bottom all through the area, but tend to be more abundant toward the middle of the flat. They also extend along the sloping inner edge of the reef behind the area where the ocean waves strike the reef.

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3.1.3.1 Section A

This section is located approximately in the middle of the area where the water is about 3 - 4 feet in depth. The bottom is composed of a mixture of sand and chunks of worn coral as well as outcroppings of flat encrusted rock that has been worn smooth by the action of flowing water. Large patches of algae (*Acanthophora* sp. and *Sargassum* sp.) as well as extensive bare areas are present with juvenile *Dascyllus albisella* being found in the latter areas. Most of the coral heads extend in a "belt" that runs parallel to the shore for an undetermined distance.

3.1.3.2 Section B

This section is a flat rock outcrop that runs parallel to the surge zone, thus acting as a barrier to the waves coming from the open ocean. It is heavily indented by crevices and channels that mostly run in a seaward direction. Coral heads of the species *Pocillopora ligulata* and *Pocillopora meandrina* are present in the area, the former species being located farther back on the outcrop away from the more immediate influence of the breaking waves. There is very little algal growth as in the more inshore section, and as would be expected, the water movement in the section is much stronger than in the inshore section.

3.1.4 *Waikiki Area*

The Waikiki area (Figure 15) is located in the waters

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off Ala Moana Yacht Harbor and extends southeastward to a position off the Royal Hawaiian Hotel. Three sections within this general area were selected for further study.

3.1.4.1 Section A

This section lies approximately 3/4 mile offshore from the Ala Moana Yacht Harbor at a depth of 70 feet. The bottom is very flat rock and is broken by very few cracks or gullies. Interspersed here and there in the bottom are patches of sand that range in size from several feet in diameter to many acres. Patches of glomerate corals (*Porites lobata*) lie in scattered locations and provide cover for large aggregations of adult *Dascyllus albisella*. Ramose coral heads such as *Pocillopora* sp. are rare and with one exception (Section 3.2.4) were never observed to harbor juvenile *Dascyllus albisella*. Long-spined sea urchins (*Echinothrix diadema*) are common in the area and were seen to accommodate considerable numbers of juvenile *Dascyllus albisella* during certain times of the year (Section 3.13). Otherwise, juveniles were very scarce in the section, being found mostly as single individuals that hid from view in holes in coral rocks.

3.1.4.2 Section B

This section is located on a sloping bottom at a depth of about 15 to 18 feet. The bottom is level with a few *Pocillopora meandrina* and *Porites* sp. coral heads protruding above it and is indented by numerous cracks, often one foot

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r more in depth. There is little sediment in the section due to the scouring action of the waves and sand-filled pockets are scarce. The section lies in the surge zone, although it is located some 200 yards seaward of the actual breaker zone. The surges are generated by unbroken ocean waves in contrast to the surge zone at Kualua where the surges are generated by waves on the landward side of the breaker zone. Juvenile Dascyllus albisella have never been seen in the section although apparently suitable coral heads are present. In this respect, the section is similar to section B at Kualua.

3.1.4.3 Section C

This section consists mostly of heads of glomerate coral of the genus Porites but was apparently almost devoid of juvenile Dascyllus albisella. Since studies on nesting behavior were carried out here, a fuller description is given under that topic (Section 2.3).

3.2 AGGREGATIONS OBSERVED IN THE FIELD

Juveniles were observed in the field under natural conditions by swimming with face mask and snorkle or with the aid of underwater diving apparatus (SCUBA). Frosted plastic sheets were used for recording underwater observations. Thermometers, salinity bottles, nets and tools were carried in a weighted bag which could be left on the bottom

[illegible]

In making observations in shallow water it was usually possible to remain on the surface of the water and count the fish. However, in the channels it was necessary to dive to the areas of the coral heads and to hold on to the bottom while the observation was being made. Fish could usually be approached to within about three feet before they would seek cover in the coral head. At this distance, the fish associated with the coral head could be seen and counted before they retreated.

One formidable problem arose in connection with counting the numbers of fish in the coral heads. It was extremely difficult to judge the size of the fish, particularly because of the continual motion of both fish and the observer. During the first few observations, an attempt was made to judge the length frequencies of the fish. However, the tendency of the fish to constantly change their positions and to intermingle with each other created a problem.

An attempt was made to identify the fish in a given head as "new fish" or "old fish" in relation to their period of residence in the coral head. The criterion for such judgements was based on the tendency for the caudal fin of very young fish to show a hyaline condition when they initially colonize a coral head. However, aquarium observations showed that the tendency for the progressive spread of pigmentation over the caudal fin was variable with the size of the fish. The potential method of determining numbers of "new fish" in a head was not reliable because some larger fish retained the hyaline condition while some of the smaller ones rapidly lost it.

The best that was accomplished in respect to identifying size changes of fish in the heads was to note that the great majority of fish associated with them were seen to increase progressively in size during the period of months when they were under observation. The increase in size of fish in both individual coral heads as well as in an area as a whole is unmistakable and has been referred to by a number of different collectors that were interviewed.

In 1961, coral heads in sections A and B at Waimanalo (Figure 16) were identified by the same numbers as in 1960. In other words, coral heads having a certain number in 1961 represent the same heads that were known by that number in 1960, except that a new population of fish was present. The head lettered "a" in section A and those lettered "a, b, c, d and e" in section B represent heads that were populated in 1961, but not in 1960. The heads lettered "s, t, u and v" in section B and "w, x, y and z" in section D are experimental heads and will be dealt with under Section 3.12.2.

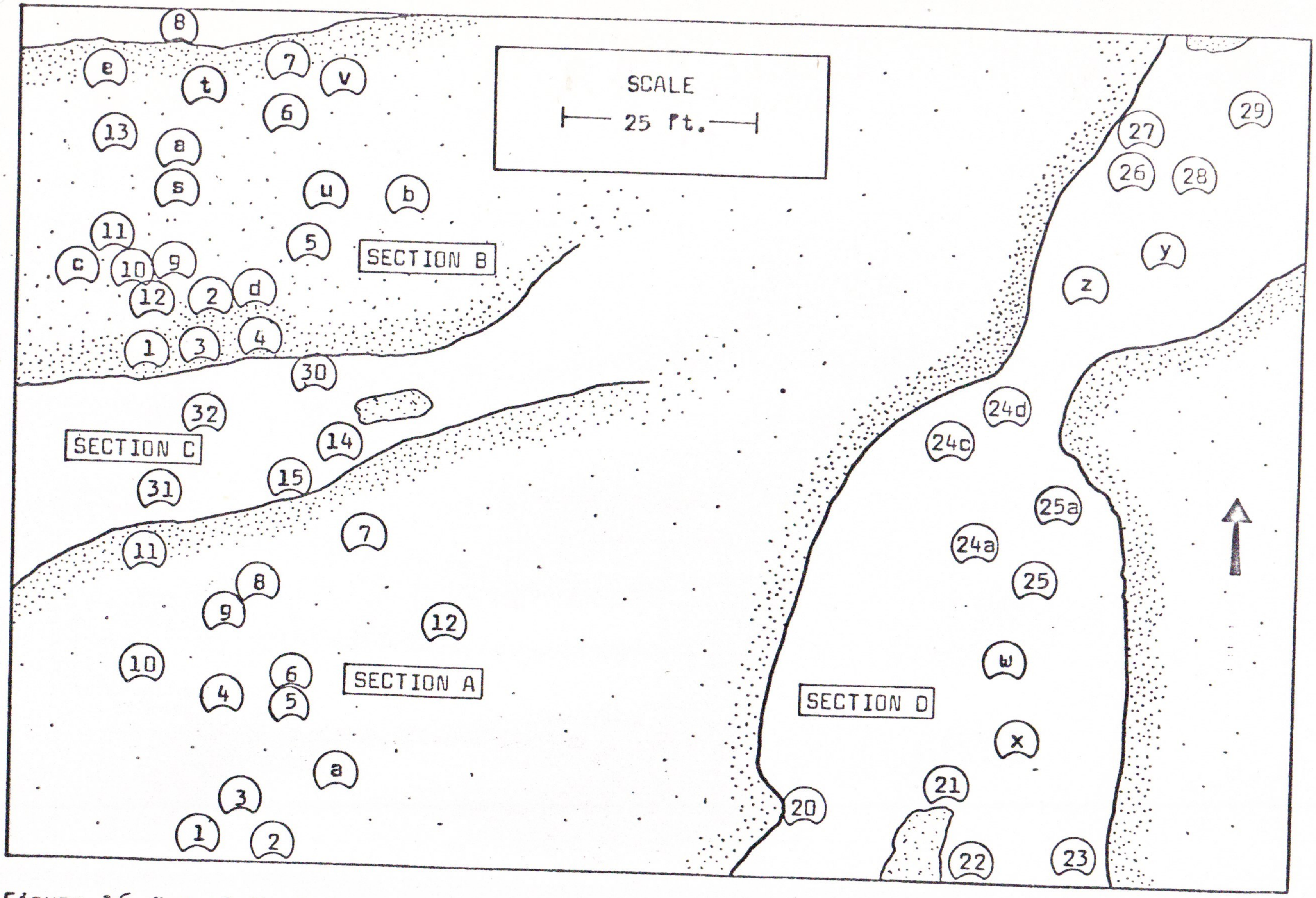

Figure 16. Map of the Waimanalo study area showing sections studied and locations of coral heads.

Coral heads were numbered as they were found and since all heads were not found at the same time, the numbering does not follow a regular pattern. The two heads known from section D in 1960 were given the numbers 22 and 23 during both 1960 and 1961 to indicate that they were the same heads that were populated part of the time during those years. Other than these two heads, all the heads with Dascyllus albisella that were found in 1961 in section D were not observed the year before.

3.2.1 Waimanalo Area

The results of the observations of numbers of fish seen at Waimanalo in 1960 and 1961 are summarized in Figures 17 and 18. In 1960 in section A, there were five coral heads (1, 2, 3, 4 and 10) that were populated by relatively large numbers of juvenile Dascyllus albisella. In contrast, section B had only three aggregations (1, 4, and 8) in which numbers of fish tended to approach those of section A. These three heads were located in deeper parts of section B that offered a habitat more like sections C and D that were a more optimal habitat judging from the numbers of fish found there. Aggregations of relatively few fish were found in the shallower central portions of section B, which in respect to surge, is a more turbulent environment. The remainder of the aggregations found in section A, which appeared to be rather homogeneous in respect to surge,

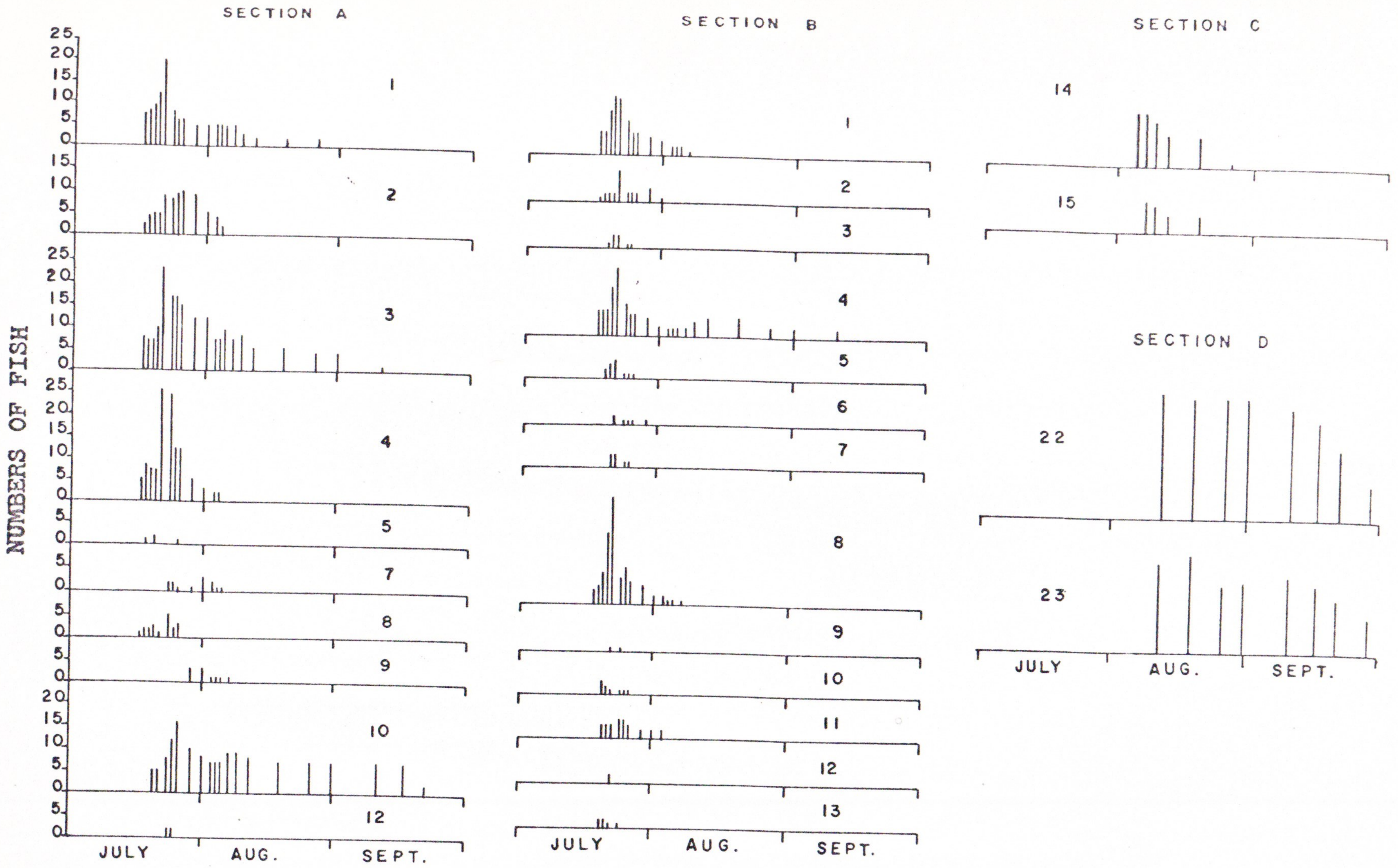

Figure 17. Numbers of juvenile *Dascyllus albisella* observed in the field at the Waimanalo study area during the summer and fall of 1960.

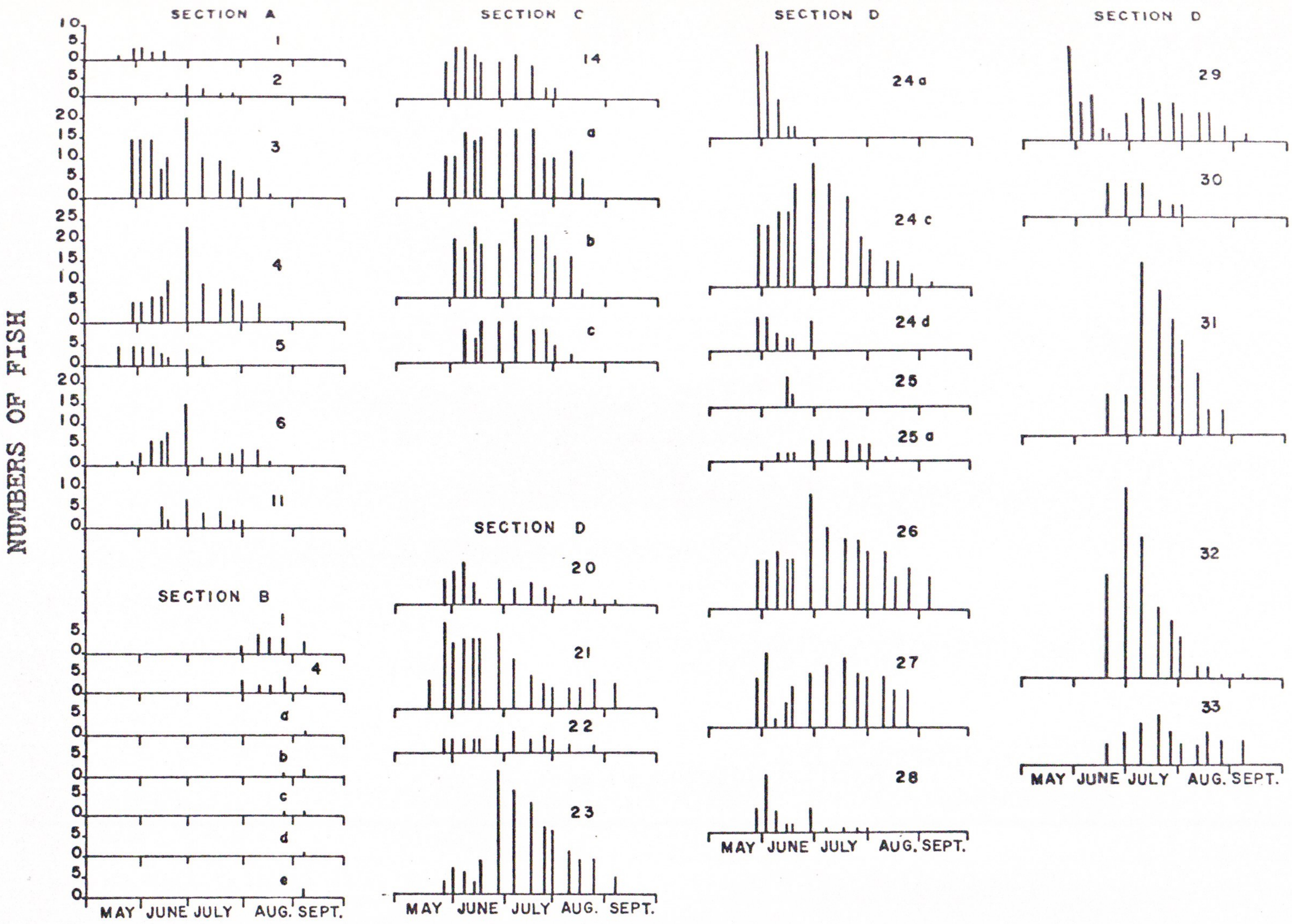

Figure 18. Numbers of juvenile Dascyllus albisella observed in the field at the Waimanalo study area during the summer and fall of 1961.

consisted of relatively few fish.

In 1960, a population peak occurred around July 20 after which there appeared to be little recruitment of juveniles. If recruitment occurred after this time, it was small since numbers of fish progressively decreased and the size of most of those fish present was noticeably larger. Numbers of fish continued to decrease through September and coral heads were almost completely devoid of fish by early October. At that time, a few free-living juveniles were seen roaming around over the bottom (Section 3.7).

It should be noted in Figure 17 that except for a 48 hour interval between July 20 and 22, daily observations were made between July 16 and 24. Therefore, the fluctuations observed are the daily increases and decreases in numbers of fish in specific coral heads. An examination of the histograms in this light shows that fish arrived at these heads daily and after a peak, the numbers in general dropped sharply. The lack of an observation on July 21 is unfortunate because of the 48 hour gap in time during which a great decline in numbers occurred. The reason for the sharp decline is not known and since there was no noticeable change in the weather during this period, it is suspected that the cause is associated with some other factor.

In 1961, another peak in numbers of fish occurred. As in 1960, aggregations seemed to decrease after one particularly large influx of fish. However, it is possible that in both years, there may have been another large influx of juveniles earlier than the time during which the first observations were made. Section 3.13 (association with sea urchins) shows three influxes of juveniles in 1961 that could possibly be related to those at Waimanalo, although the dates involved are not exact enough to pin-point the time of arrival. In any event, these sudden increases in numbers of juvenile fish may indicate the presence of some sort of cyclic phenomenon such as lunar periodicity as reported for Abudefduf abdominalis (Helfrich, 1958), Acanthurus triostegus sandvicensis (Randall, 1955), and Kuhlia sandvicensis (Tester and Takata, 1953). However, the irregularity of observations prevented the acquisition of data that might have related such fluctuations in numbers with lunar periodicity.

As stated previously, the sharp decline in numbers of fish soon after a peak was reached is not thought to be related to weather conditions. The fact that the same phenomenon appeared in both sections A and D where surge conditions are quite different (Section 3.9) indicates that some biological factor may be responsible. It is possible that the crowded conditions that occur at night when fish retreat into the coral head may lead to excessive fighting which results in the smaller fish being driven away from the head (Section 3.2) where they would be vulnerable to predation. Small juveniles might be prone to readily leave a coral head since they are at a stage in which they are probably returning from a planktonic existence and are still disposed toward moving around.

Figure 18 shows a population situation similar to that of 1960 (Figure 17). Section A again had aggregations with larger numbers of fish and had the same number of heads populated as section B. However, most of the heads in section B had only one or two fish, and the majority of heads occupied were different from those occupied in 1960. The two heads that had the most fish in section B were the same heads as those that had the most fish in 1960.

A situation was noticed in sections C and D that was not seen in other areas of the environment. Numbers 24a, 24c, 24d, 25, 28 and 30 (Figure 18) represent coral heads of the species *Porites pukoensis* that usually do not have associated aggregations of juvenile *Dascyllus albisella*. Three of these heads contained fish for a considerable length of time and 24c had a very sizable aggregation of fish. Since *Porites* of this species is also found in areas of greater surge, it would seem possible that the milder conditions presented by the deeper channel in some way enable fish to survive in the latter areas where they are associated with a species of coral that elsewhere may provide suboptimal shelter.

3.2.2 Kaneohe Bay Area

Since this area was not studied with an effort comparable to that focused in the Waimanalo area, there are relatively few data available in connection with aggregations of fish. Although observations in the area were relatively few, the length frequency distributions in Figure 19 show that coral heads there built up large aggregations of fish. Five of the eight collections made on October 1, 1960, had numbers of fish that were comparable with those found in aggregations in sheltered areas such as sections C and D at Waimanalo and section B at Waikiki.

The area is known among collectors as a place that abounds in juvenile *Dascyllus albisella*. Mr. Lester Zukeran has reported that on many occasions he has captured up to 50 or more juveniles from a single coral head. In the early days of the investigation, the author himself has seen large aggregations of fish that were not seen again due to failure to properly locate the coral heads.

3.2.3 Kualua Area

A total of four collections of fish were made at Kualua (Figure 20) from section A where the water was less

COLLECTION AREAS OF FISH
RECORDED IN FIGURE 19.

1. Pier 7, Honolulu Harbor, February 2
2. " " " " February 20
3. Coconut Island, March 16
4. " " May 1
5. " " May 1
6. " " June 15
7. " " June 20
8. Waimanalo, June 27
9. Coconut Island, July 10
10. " " July 16
11. Ala Wai Harbor, July 24
12. Waimanalo, August 6
13. " August 6
14. Ala Wai Harbor, August 6
15. Coconut Island, September 10
16. " " September 10
17. Kaneohe Bay, October 1
18. " " October 1
19. " " October 1
20. " " October 1
21. " " October 1
22. " " October 1
23. " " October 1
24. " " October 1

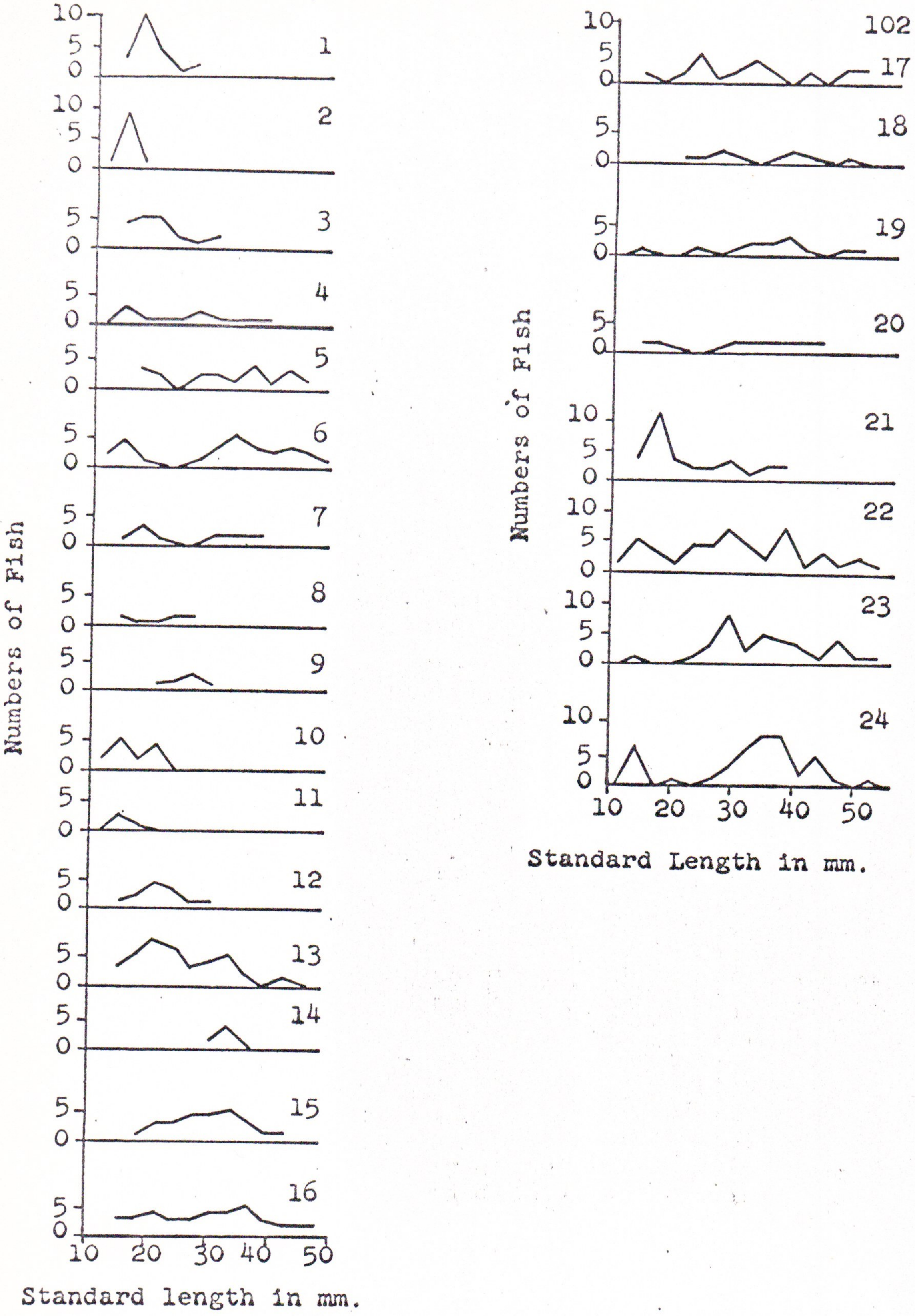

Figure 19. Length frequency distributions of fish captured during 1960. Area and date of capture are located on the facing page.

COLLECTION AREAS OF FISH
RECORDED IN FIGURE 20.

1. Coconut Island, January 6
2. " " January 7
3. " " January 7
4. " " January 11
5. " " January 18
6. " " January 18
7. " " January 18
8. Kaneohe Bay, March 11
9. Waimanalo, May 20
10. " June 14
11. " June 14
12. " June 20
13. Waikiki, June 23
14. Waimanalo, July 1 (no. 1)
15. " July 1
16. " July 1
17. " July 9
18. " July 9
19. " July 9
20. " July 9
21. " July 12
22. " July 14
23. Kualua, July 16
24. " July 16
25. " July 16
26. Waimanalo, July 20
27. Kualua, July 27

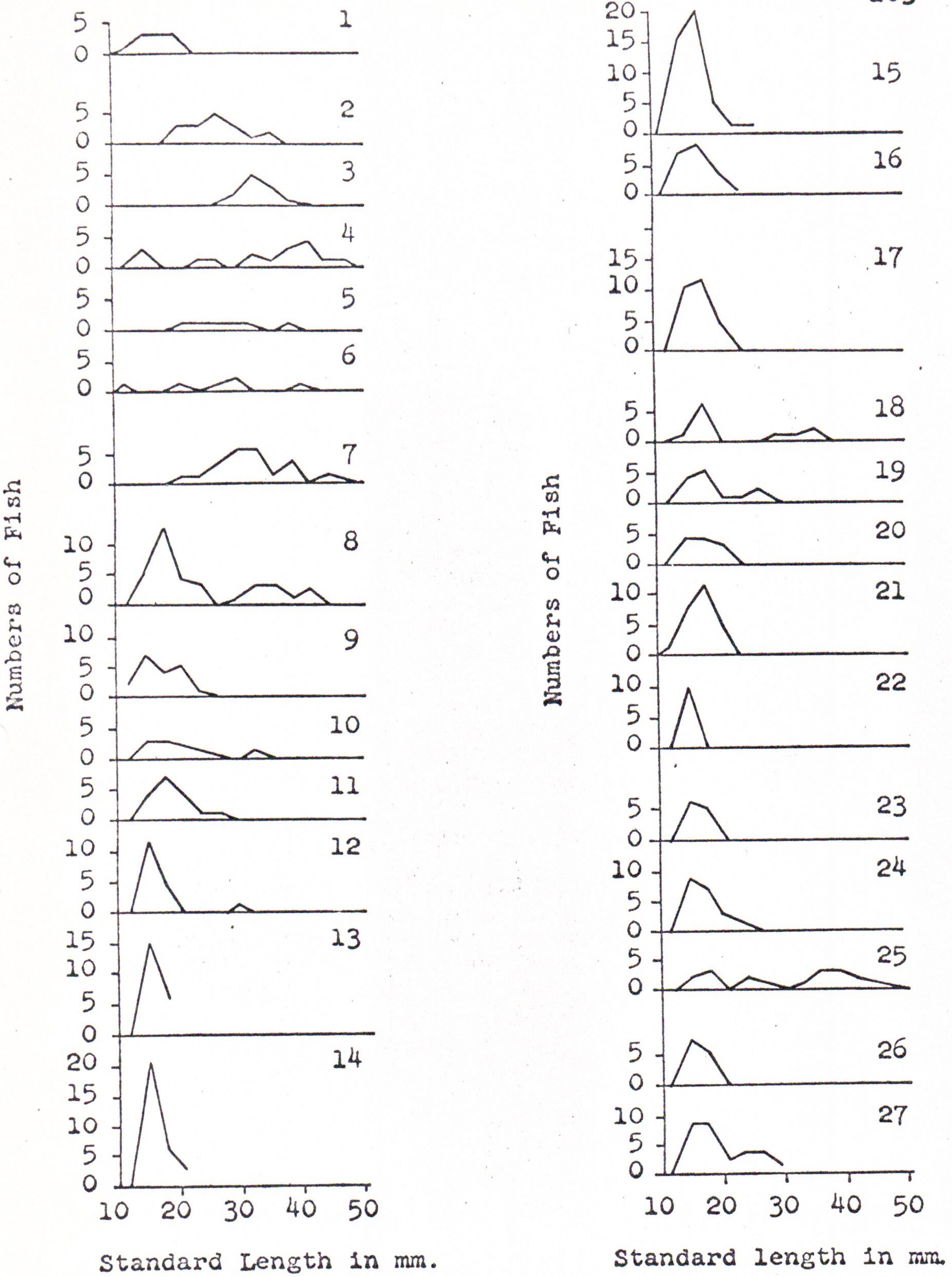

Figure 20. Length frequency distributions of fish captured during 1961. Area and date of capture are located on the facing page.

turbulent. Two searches were made in this section with a total of 33 occupied heads being found. Numbers of fish per coral head ranged from 2 to 23 with an average of 12 fish per head. The "fish zone" comprised a belt extending parallel to the surge zone about 300 yards farther to seaward. In numbers of fish and behavior of the aggregations, section A appeared similar to section A at Waimanalo, which appears to be an intermediate type of habitat between surge zones and areas of calm water.

The coral heads in section B were also observed during the time of the above surveys. With two exceptions, they were found to be devoid of fish. In one case, a single fish was observed associated with a Pocillopora ligulata coral head while three others were seen in another head of the same species. An estimated 50 coral heads were examined in an area about 300 yards in length and about 150 feet in width, which comprised a larger area than the inshore section, but contained fewer heads than were examined in the inshore section.

Few fish were seen during observations in section B where surge was strong. A number of other incidental observations have been made in this and similar areas, but juvenile Dascyllus albisella have always been scarce or non-existent.

3.2.4 Waikiki Area

The calm, deep offshore waters of section A are populated by relatively few juvenile *Dascyllus albisella*. Most of the fish in this section have been found at certain times associated with poisonous sea urchins. As many as 81 fish have been observed at one time with 23 urchins. Other juveniles in the section live in holes that perforate many of the dead glomerate coral heads found there. However, very few fish were found in the latter habitat probably because they were scarce there or because they were difficult to find in such locations. Very few of the larger sized juveniles were seen and it was assumed that few fish had originally been present or that a high degree of predation occurred on the young that had been present.

An almost complete absence of ramose coral heads from the section makes it difficult to judge whether conditions otherwise would be suitable for colonization by juveniles. In one instance a single coral head of the species *Pocillopora meandrina* was found growing two feet off the bottom on the fluke of an old anchor. It was found that this head, which afforded relatively poor protection because of its small size as well as its widely separated branches, always had an associated population of juvenile *Dascyllus albisella*. Figure 21, taken off Waikiki at a depth of 70 feet, shows this coral head. The head was essentially out of the

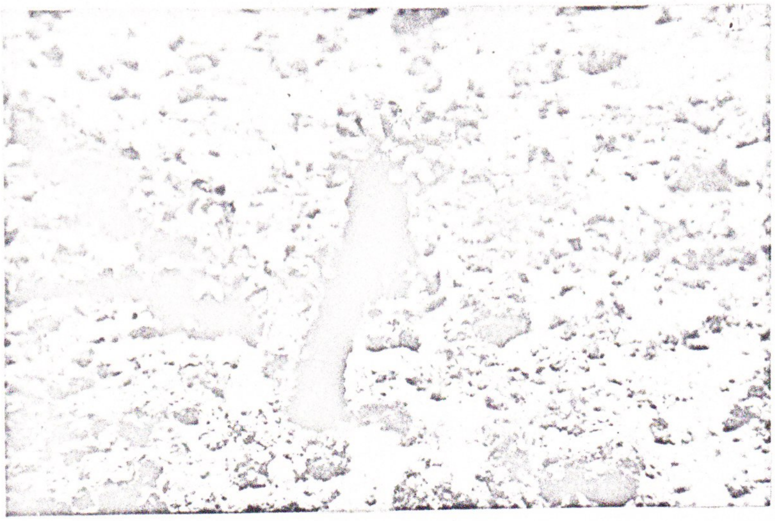

Figure 21. Pocillopora meandrina coral head growing on fluke of encrusted anchor. This coral head was continually populated by juvenile Dascyllus albisella throughout the period of observation.

area of predation (Section 3.16), which is an indication that young could survive in the section as far as hydrographic features are concerned. The very large aggregations of fish that resulted from the planting of coral heads in the section proves that fish can live there (Section 3.12.1).

It should be noted that individuals or small groups of Dascyllus albisella are occasionally found associated with isolated rocks or other conspicuous objects. However, because of the continual presence of fish, the situation noted above indicates that conditions were favorable for colonization by an aggregation of fish.

Section B, in the surge zone, also appears to be devoid of juveniles. Apparently suitable coral heads are present in the section, but are uninhabited. Many hours of observation in this section as well as in more or less identical surroundings farther up and down the reef along the Waikiki area have failed to disclose any fish. Therefore, it is concluded that the section represents an unfavorable habitat for young of this species.

3.3 LENGTH DISTRIBUTION OF JUVENILES

Fish were usually captured by placing a net over an occupied coral head which was then brought to the surface intact with fish. In some cases it was necessary to catch fish individually when they were found occupying cavities in rocks, etc. Few catches were made in this manner for it was time consuming and relatively unrewarding. Fish occupying sea urchins were caught by rapidly swinging the urchin through the water and catching the fish in a net when they swam out. A plastic bag was used to hold the fish until shore could be reached and the fish could be transferred into buckets.

During the summer months, collections were made sporadically in many different localities while working on other phases of the problem. During the months of November through April, the Waimanalo area was visited each month, but no fish were found. Fish collected during these months were caught during irregular visits to Coconut Island. Collections were made outside of immediate test areas and areas under observation. They were occasionally made by placing coral heads on the reef near Waimanalo and collecting fish that came to occupy them.

Figures 19 and 20 show length frequency distributions of fish caught during 1960 and 1961. An examination of these figures, formed by grouping fish lengths by 3 mm. intervals, shows that juveniles were found in coral heads during most of the year. Greatest numbers of very small juveniles were found during the late spring and early summer months. These periods indicate that juvenile *Dascyllus albisella* tend to enter inshore areas later than *Abudefduf* *abdominalis*, which appears in the early spring months in greatest abundance (Helfrich, 1958). However, sampling of *Dascyllus albisella* was inadequate to establish this as a fact.

In some species, it is possible to trace the influx of new groups of fish and to determine average growth rate by the progression of modes in the length frequency distributions from time-series samples. No modal progression appears in Figures 19 or 20. The modal groups show that new fish appeared throughout a period of over a month during the summer of 1961 (Figure 20). Such constant increases lead to a potential blending of modal groups such as appear in Figures 19 and 20. Undoubtedly there is also an interaction between recruitment and loss of fish through predation together with normal movements from one head to another, that further obscure the picture. In addition to this, although juvenile *Dascyllus albisella* are not uncommon, they are not abundant enough to furnish sufficient numbers for accurate population analyses. They occur in many different areas, but areas of dense, accessible concentrations are relatively scarce. There is a possibility that modal groups could be studied by attracting aggregations to certain areas such as was done at Waikiki (Section 3.12.1).

3.4 INITIAL ENTRY OF JUVENILES INTO CORAL HEADS

In the spring months coral heads became populated by juvenile *Dascyllus albisella* which appeared to be about the same size in different locations on the reefs. It is likely that at that time of the year, the condition of various physical and biological factors combined to produce a movement of juvenile fish from the pelagic environment of the ocean to the inshore reef areas. In order to determine the size of newly arrived fish, it was necessary to find new aggregations in coral heads that were known to be uninhabited at some previous date. A number of observations of this kind were made and were included in Figures 19 and 20.

These aggregations are shown in Figure 20 by collections made on June 20, July 1 (no. 1), and July 14, 1961. The coral heads in which these fish were collected were known to be without fish one week prior to the time that the fish were collected. The distribution shown for June 23 represents another newly arrived population that was sampled from sea urchins uninhabited a week earlier. The February 20 distribution in Figure 19 represents a new population of fish that was caught adjacent to a piling in Honolulu Harbor. The fish in these collections ranged from 12.8 mm. to 21.1 mm. and the average length was 14.7 mm. Data for these collections are summarized in Table 10.

TABLE 10. LENGTH FREQUENCY DISTRIBUTION OF JUVENILE DASCYLLUS ALBISELLA WHEN FIRST COLONIZING CORAL HEADS.

	Frequency				
Fork Length in mm.	1960 Feb. 20	1961 June 20	1961 June 23	1961 July 1	1961 July 14
12	-	1	-	-	-
13	-	1	4	1	3
14	5	6	5	8	1
15	1	5	8	12	6
16	4	2	3	3	-
17	-	2	1	1	-
18	-	-	-	0	-
19	-	-	-	2	-
20	-	-	-	0	-
21	-	-	-	1	-
Mean Length	15.0	14.7	14.6	14.9	14.2
Total Number	10	17	21	28	10

Average length = 14. 7 mm.

The question of how newly arrived fish locate coral heads is difficult to answer. It could be argued that juveniles being swept into the shallow reef habitat merely settle out in various places and those that happen to reach coral heads survive while others have less protection and are eaten by predators. However, as will be shown later (Section 3.9), the existence of surge probably drives newly arrived fish off the shallow portions of the reefs and the fish congregate in the deeper portions of the reef. The constant association of juveniles with coral heads strongly indicates that they are attracted to them in some way in the field. On two occasions juvenile fish associated with glomerate coral heads almost immediately swam to ramose coral heads placed close to them. In the absence of coral heads, they have been seen to occupy other objects such as sponges or clusters of sabellid worm tubes which essentially present an arborescent or ramose appearance. In aquaria, juveniles will occupy coral heads to the exclusion of other objects that are introduced.

Macfadyen (1957) pointed out that animals having patchy distributions must have highly specialized methods for detecting their habitats. It is probable that coral heads act as visual sign stimuli to juvenile *Dascyllus albisella*, but laboratory experiments designed to shed further light on this hypothesis were inconclusive. It is possible that the coral heads as a whole might represent a configurational organization of certain sign stimuli, or "gestalt", which is the usual situation encountered in the field (Tinbergen, 1951). It is likely that the regular pattern presented by the light branches and dark interstices would offer a "recognition mark" that could be seen by a fish from a considerable distance, thus offering a first "sign" in guiding fish to adequate shelter.

The type of terrain on which a coral head is located might have an important bearing in relation to a fish's orientation to its characteristic shelter. This could be one factor influencing the build-up of populations in calmer waters. In such areas, sand tends to settle out and form pockets or a smooth sandy bottom. Areas of this kind have interspersed stretches of flat rock bottom on which coral heads grow. Under these conditions it becomes relatively easy for a human observer and presumably a fish to visually detect coral heads as they tend to stand out from the sandy surroundings. Juveniles coming into an inshore area might more easily detect the heads and thus build up the large aggregations that are found in such locations.

Coral heads are less evident on more jumbled stretches of rock bottom both because their color tends to blend with the surroundings and also because of the presence of rocks and non-ramose coral heads with which the ramose types may be confused. Under these circumstances, young *Dascyllus albisella* might not be able to detect the presence of a head as readily and might be prone to move elsewhere until an area is reached where coral heads are more easily seen. Such interactions are influenced by surge which drives fish from more turbulent areas where coral heads are actually more conspicuous on the wave swept bottom.

In view of these considerations, it is probable that the development of an association with coral heads might involve, among other things, an interaction between surge (or surge associated factors) and an orientation to coral heads. Juvenile *Dascyllus albisella* might arrive in surge zone areas from the pelagic region and be immediately swept away from coral heads in the area. They might then be transported by currents to milder shallow areas where they are able to tolerate the conditions of surge for varying lengths of time. A certain proportion of these fish might leave such areas and eventually arrive in the quieter, deeper areas where conditions result in greater survival and where there are fewer rheotactic stimuli that might cause them to leave. The photographs in Figures 22 and 23 show the isolated nature of coral heads that may build up large aggregations of juvenile *Dascyllus albisella*. Figure 22 shows juvenile *Dascyllus reticulatus* with the coral *Pocillopora eydouxi* and Figure 23, *Dascyllus aruanus* with

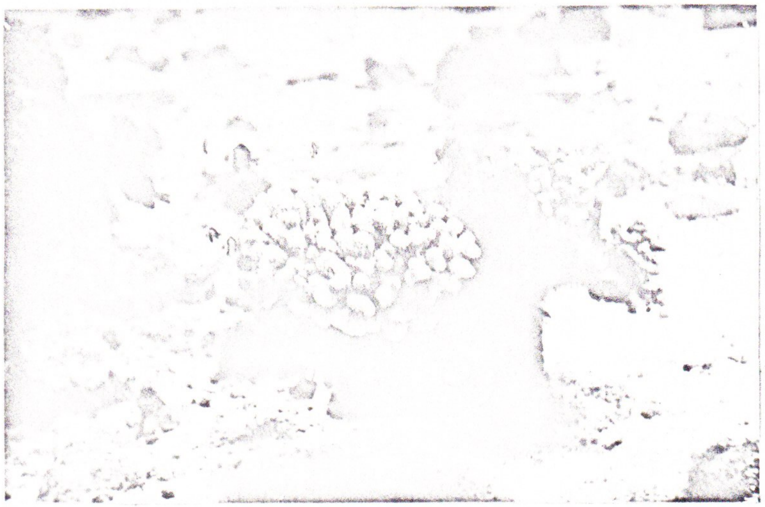

Figure 22. *Pocillopora* sp. coral head on intermittent sand-rock bottom that isolates it from surrounding coral and rock. Head is populated by juvenile *Dascyllus reticulatus*.

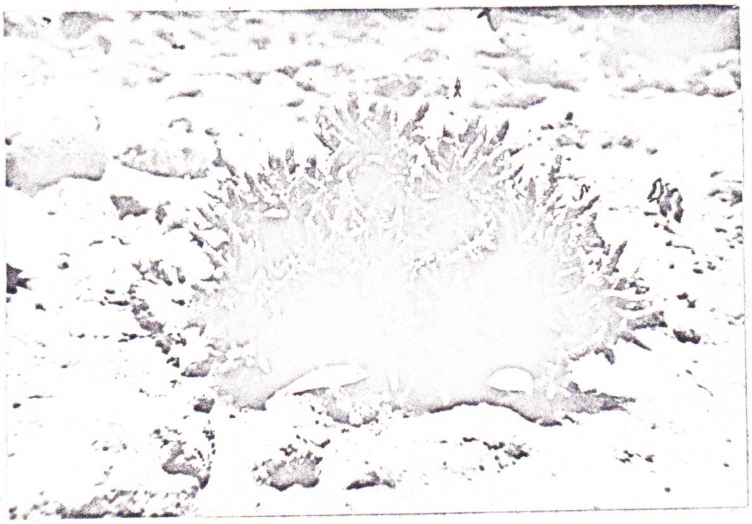

Figure 23. *Acropora* sp. coral head on intermittent sand-rock bottom that isolates it from surrounding corals and rock. Head is populated by juvenile *Dascyllus aruanus* (middle right).

Acropora echinata. Although the photographs were made at Eniwetok Atoll at a depth of 6 feet, they well illustrate the situation that is found in Hawaii.

3.5 ABUNDANCE OF FISH IN RELATION TO SIZE OF CORAL HEADS

An effort was made to determine whether or not a correlation existed between the size of coral heads and the numbers of fish inhabiting them. Accordingly, the volume of the internal spaces was determined and used as a criterion for the size of the head. This was accomplished by placing the head in a plastic bag, and immersing it so that the outside water pressure forced the bag against the periphery of the head. Measured amounts of water were then poured into the bag, thus filling up the spaces between the branches of the coral. The numbers of captured fish that had been associated with the coral head in the field were then compared with this volume.

Two such comparisons were made; one utilized 17 coral heads chosen at random from Kaneohe Bay and reef areas near the town of Waimanalo, and the other utilizing 20 heads that were observed near the Waimanalo study area. In the latter comparison, average numbers of fish that appeared throughout the summer of 1961 were compared with the volumes of the coral heads with which they were associated. The volumes of the latter coral heads were judged by comparing them with coral heads of known volume held alongside them.

The scatter diagrams in both Figures 24 and 25 show no significant relationship between total or average numbers of fish and volume. The scatter of the points shows a more or less random distribution with a slight increase in numbers of fish with increase in size of coral head in the Kaneohe data. There appeared to be some increase in average numbers of fish with larger coral heads at Waimanalo. It should be noted that in the latter case fewer heads of a larger size were examined.

These results do not preclude the possibility that such a correlation might exist. However, they support the impression that if a correlation does exist, it is not of a magnitude that permits easy recognition in the field.

3.6 ABUNDANCE OF FISH IN RELATION TO LOCATION OF CORAL HEADS

Figures 17 and 18 show that the size of fish populations in coral heads is related to the area in which the head is located. In 1960, the heads in section A at Waimanalo were populated by greater numbers of fish than those in section B. It is most interesting to note that those heads having the most fish in section B (heads 1, 4 and 8) were located at the deeper edges of the section where the surge

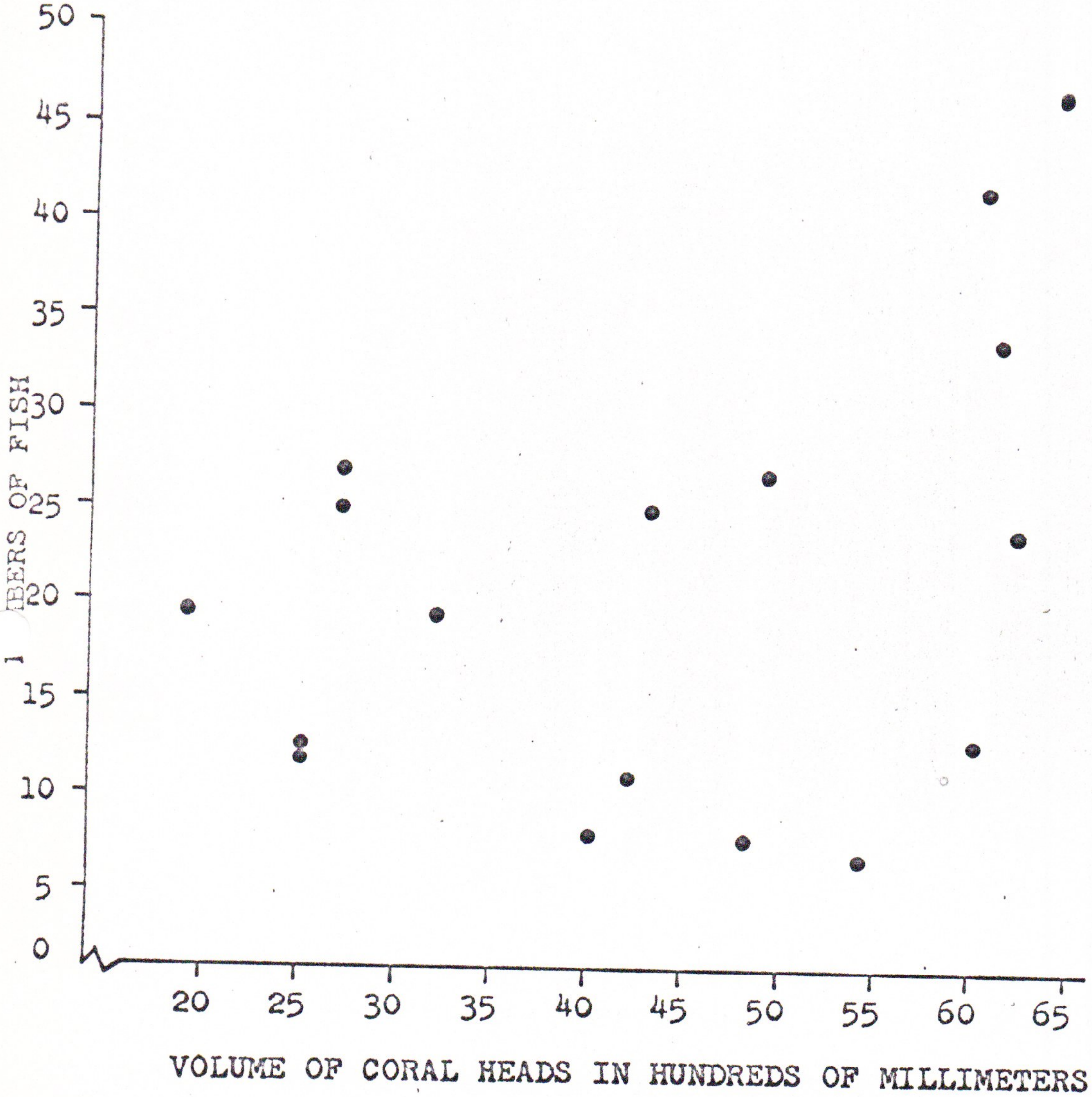

Figure 24. Relationship between numbers of fish and volumes of coral heads from which they were captured in Kaneohe Bay.

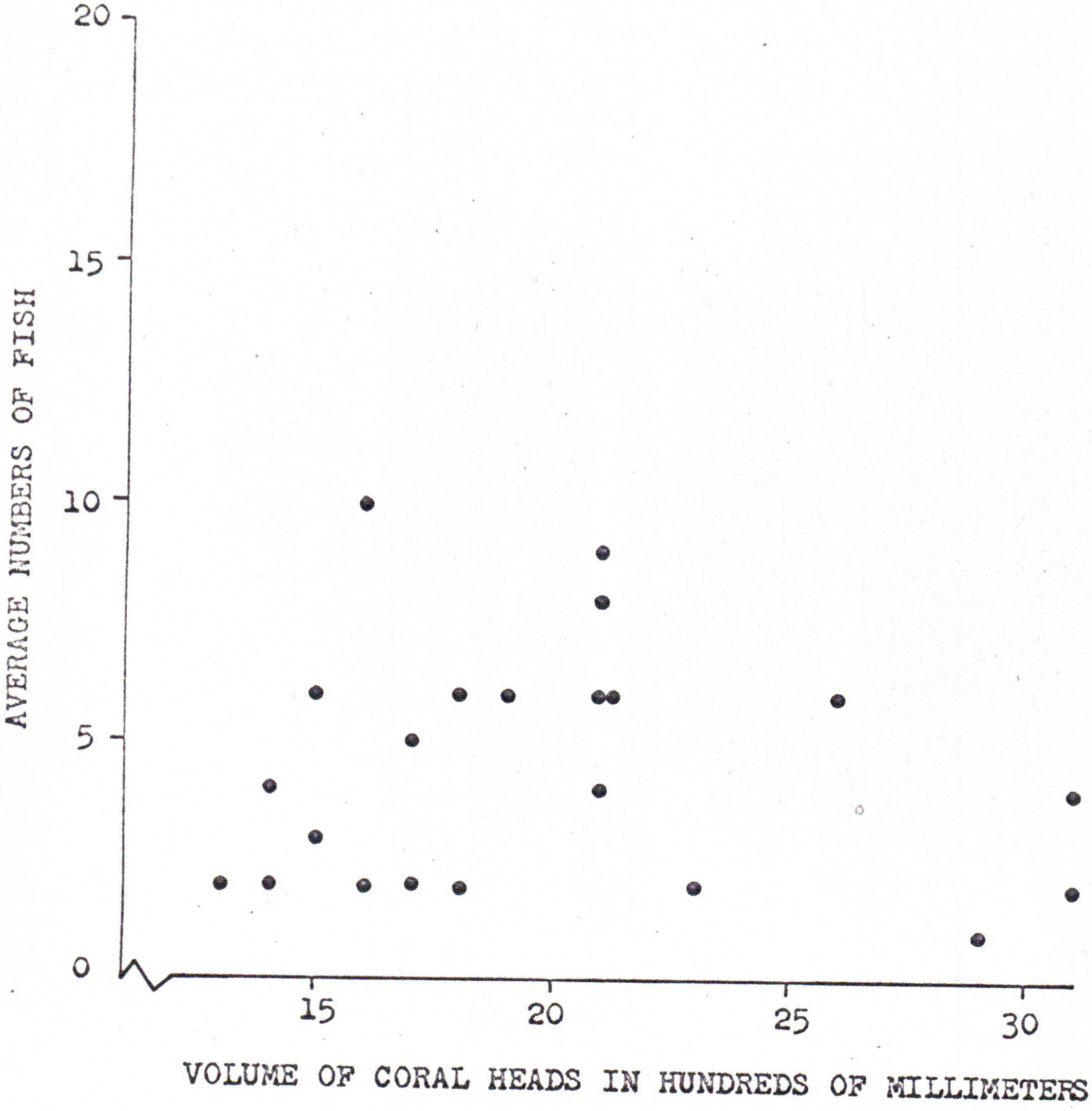

Figure 25. Relationship between average numbers of fish observed at Waimanalo during 1961 and volumes of coral heads in which they were living.

was reduced (Section 3.9.3). Head number 1 was at the sloping north edge of the section where the water was deeper and heads number 4 and 8 were in still deeper water at the edge of section C. Section A on the basis of surge velocities appeared to be a less rigorous habitat than section B. In 1961, the situation was similar with section A having much greater numbers of fish.

Sections C and D, which had relatively calm water and coral heads isolated in the sand, had heads that were populated by considerable numbers of fish as seen by the few observations made there in 1960. In 1961, numbers of fish at C and D far surpassed numbers found in sections A and B. The tendency for flat areas with isolated coral heads and relatively little surge to build up large populations of fish is also shown in Figure 35 for section A at Waikiki. Figure 19 shows the sizable numbers of fish captured at Kaneohe Bay, an area that also fits the above description.

3.7 BEHAVIOR OF FISH IN RELATION TO CORAL HEADS

3.7.1 General Behavior

Juvenile Dascyllus albisella show a very definite behavior in relation to their coral head habitat. The fish spend practically all of the daylight hours feeding outside of the coral head. However, they remain very closely associated with it, and are able to regain quickly the safety of the interstices between the branches when they become frightened. This behavior pattern is made up of a number of components.

Juveniles tend to cluster in the immediate neighborhood of coral heads in a pattern that varies with a number of factors. The shape and dimensions of an aggregation change with the velocity of the current. When current or surge is strong, the individuals of an aggregation group together and maintain their position within a few inches of the coral head on the upcurrent side. This position, which is usually about midway below the top of the head and above the side, strongly contrasts with behavior during periods of slack water. In still or slow moving water, fish tend to fan out in an umbrella shape on all sides as well as over the top of the head.

The composition of the aggregation has a definite organization that is related to the size of the fish. The largest fish maintain positions up to two feet from the head whereas the distance that progressively smaller fish maintain decreases with the size of the fish. In this position, the largest fish extend farthest into the current and thus are first to come into contact with the planktonic organisms on which they feed. It is evident that these fish would be more vulnerable to attacks by predators.

Some aggressiveness of larger fish toward smaller fish is evident when the aggregation is feeding. This indicates that the order of the aggregation is maintained, partially at least, by size. During those short periods when fish have taken refuge within a head, they vigorously chase each other with quick darting movements. As the larger members begin to make quick exploratory darts outside the head, the aggressiveness decreases and practically ceases with the full establishment of the feeding complex.

The distance that fish maintain between themselves and the shelter of the head is modified by the current to which they react by staying closer as the velocity increases. For the first month or so they slowly increase the distance at which they feed from the head while maintaining a more or less normal feeding pattern. As they grow larger in size, they sometimes cease to feed when they are two feet or more from the head and descend to the bottom. At this time single larger fish or small groups of larger fish may continue to another nearby head where they may remain for a short time, or they may immediately return to the former head. These movements occur as fish begin to leave the commensal stage of their existence and become free-living. The reduced numbers of larger juveniles in collections presumably result from this type of behavior.

In areas where the coral head is located over a sandy bottom, juveniles of a given size normally stray much farther from the head. Occasional sorties after particles of food may take an individual a foot or more beyond the rest of the aggregation. Under such conditions, the entire aggregation may gradually begin to stray farther away from the head.

The increase in distance between fish and coral head serves a number of functions. As fish grow larger it is apparent that they literally outgrow their shelter, becoming too large physically to fit into the interstices of most coral heads. This reduces the effectiveness of coral heads as shelter. Fish apparently relocate in areas where more effective kinds of shelter are available.

The greater distance between individuals that results from this behavior helps to reduce the effects of certain density-dependent factors such as fighting and shortage of food, which otherwise might result in a more rigid control of numbers of fish. When currents and surges are reduced as a result of changes in the weather or by fluctuations in the tidal cycle, the amount of water that flows past a coral head is also reduced. The compensatory activity of fish that leads to greater dispersal under such conditions allows each fish a larger volume of water from which to seek food. This would be of particular benefit to very small fish that tend to stay closer to the head, and eat what food is left after the larger fish have sorted out the plankton (Section 3.8)

3.7.2 Distance Maintained Between Fish and Coral Head

Distance measurements were made using heads 3, 4 and 6 at section A at Waimanalo since they were relatively close together and did not require the use of diving apparatus. The distances maintained by the largest fish were measured since they offered a better reference point than the inner members of the aggregation and also because they represented those fish that were in the stage of transition between a commensal and free-living state. Measurements were made by placing a ruler on the bottom under the coral head and recording the distance in inches between fish and coral head. Recordings were made at 10 second intervals over a total period of five minutes. A sufficient time was allowed to enable the fish to resume their feeding activity before measurements were made. There were no indications that the behavior of the fish was influenced by the observer.

The distance between fish and coral head varied because of the presence of unusually strong series of surges, which fish could not always effectively swim against. The distance during back-surges was not measured since these occurred during a relatively small percentage of the time. These variables were excluded from the data by halting the observations during the time when they were operating.

Observations were made between June 4 and August 11, 1961, and the distances were plotted against time (Figure 26). The significant regression ($P < 0.01$) shows the increasing distance between fish and coral heads with time that eventually results in the transition from commensalism to the free-living state. As shown by the low average distance on July 27, and by the large average distance on August 11, there are times when fish remain closer to the head and times when they move farther away. Such deviations result from differences in water velocity with fish remaining closer to the heads in swifter water.

3.8 SELECTIVITY IN FEEDING

The established fact that larger fishes eat larger organisms applies also to Dascyllus albisella. The examination of stomach contents showed that larger organisms eaten by the larger juveniles were also eaten in reduced numbers by smaller fishes in the same aggregations. Therefore, the question arose as to whether or not the smaller fish would eat more larger organisms if the larger fish were not present to "screen" them out of the plankton before the smaller fish could eat them. To find an answer to this question, it was necessary to sort fish collections into two groups for stomach analysis.

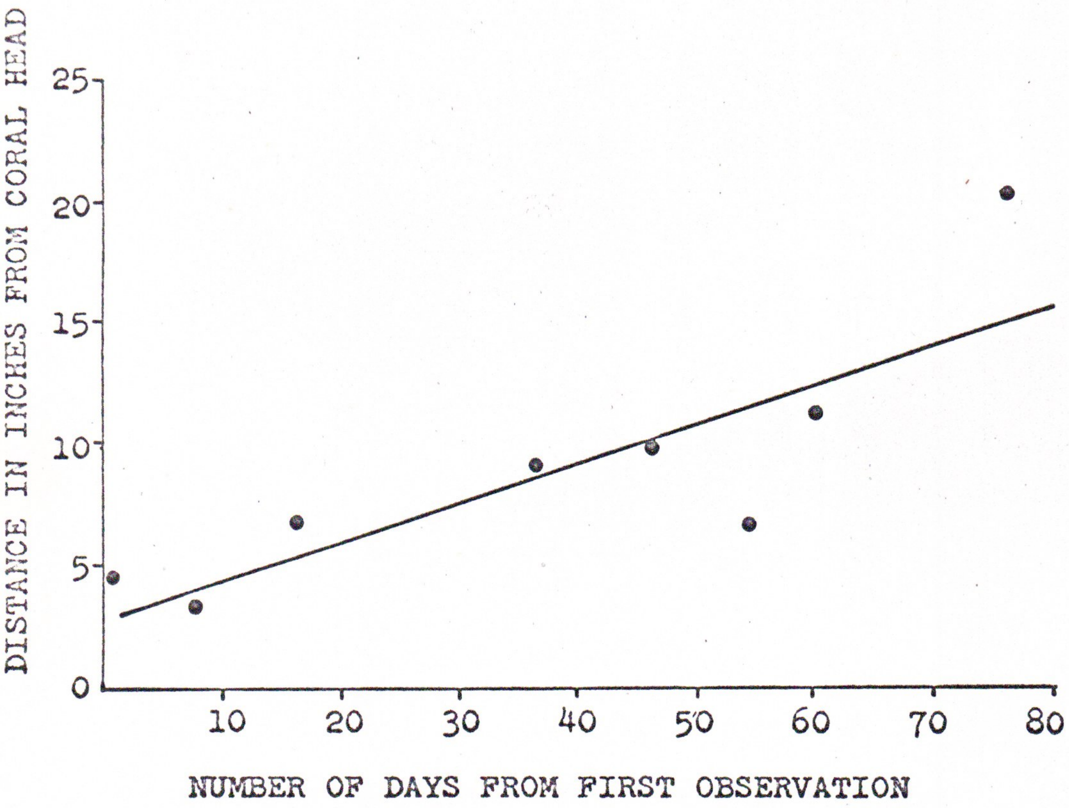

Figure 26. Increasing distance from coral heads maintained by juvenile Dascyllus albisella during the summer of 1961.

Individual aggregations collected from single coral heads that contained relatively small fish that were few in number were sorted into one group. In these small aggregations, fish would have had less competition from the few larger individuals and therefore would have been free to select larger organisms. If these fish had selected larger organisms, their stomachs should have contained greater percentages of larger organisms than smaller.

The second group contained aggregations collected from single coral heads that contained many larger fish, as well as smaller ones. In this case, it was expected that the larger fish would have selected the larger organisms leaving the smaller ones for the smaller fish which should have contained a relatively small percentage of larger organisms.

The stomach contents of 232 juveniles were analysed by determining the kinds and weights of organisms consumed. Similar organisms were grouped for each collection and weighed on a chainomatic balance after excess moisture had been removed. The data were arranged in Table 11 to show the percent of each type of organims that was contained in the stomachs of fish of different length classes.

The data for both groupings show a more pronounced trend for copepods than for the other organisms. In both groups the larger fish ate a smaller percentage of copepods

Standard Length in mm.	Weight in Grams Copepods	% by Weight	Weight in Grams Ascidians	% by Weight	Weight in Grams Shrimp-like Organisms	% by Weight	Weight in Grams Annelids	% by Weight	Total No. of Fish
Collections Containing Mostly Smaller Fish									
11-15	0.105	68	0.057	17	0.027	14	0.002	1	46
16-20	0.472	70	0.136	20	0.043	6	0.019	4	46
21-25	0.313	54	0.211	36	0.037	6	0.018	4	24
26-30	0.287	58	0.113	23	0.091	18	0.005	1	16
31.35	0.193	54	0.084	23	0.066	18	0.016	5	9
Collections Containing Mostly Larger Fish									
11-15	0.048	82	0.002	3	--	--	0.009	15	13
16-20	0.186	93	0.013	7	--	--	--	--	16
21-25	0.275	74	0.084	23	0.004	1	0.006	2	18
26-30	0.505	66	0.134	18	0.069	9	0.051	7	25
31-35	0.999	62	0.423	26	0.107	7	0.079	5	26
36-40	0.552	33	0.895	53	0.166	10	0.073	4	20
41-45	0.316	24	0.668	52	0.202	16	0.108	8	13
46-50	0.160	22	0.484	65	0.095	13	--	--	6

TABLE 11. WEIGHT AND PERCENTAGE BY WEIGHT OF VARIOUS FOOD ORGANISMS FOUND IN STOMACHS OF JUVENILE *DASCYLLUS ALBISELLA*.

which means that a concomitant increase occurred in percentage of other larger organisms eaten. However, in the collections containing mostly smaller fish with few larger individuals for competition, the smaller fish ate considerably less copepods and more larger organisms than did fish of comparable size in collections where many larger individuals were present. It is evident, therefore, that when considerable numbers of larger fish were present, they "screened" larger organisms from the plankton, leaving the smaller ones for the smaller fish.

It is reasonable to suppose that smaller fish would have to eat smaller organisms because of physical limitations in the size of the mouth. An examination was made of the size of the gape of juvenile Dascyllus albisella in relation to the size of the larger organisms ingested. It was found that the smaller sized juveniles used in this work had no physical limitations in mouth size.

The method by which Dascyllus albisella select their prey is difficult to evaluate. There would seem to be little doubt that this species is a visual feeder. Its quick reactions to surge in maintaining its position relative to the coral head as well as its ability to dash quickly in and out of confined spaces indicates a very well developed visual system that is most likely important in feeding. The importance of olfaction in feeding in such a turbulent environment would seem to be negligible, although Randall (1955) performed a brief experiment in which another pomacentrid fish, *Abudefduf abdominalis*, appeared to be able to detect odors in the water. Hiatt and Strasburg (1960) referred to several species of pomacentrids as having selected their food by visual means, although these observations were apparently made in the field. Since juvenile *Dascyllus albisella* remain close to coral heads, there would seem to be little utility connected to a sense of smell because the fish could not move far enough to find the source.

Although juvenile *Dascyllus albisella* living in coral heads cannot be compared in every respect with free-living plankton feeders, it is apparent that they are confronted with a number of similar problems in relation to their predator-prey relationships. The actual catching of prey is probably related to abundance of particular organisms that happen to be present in the water. This tendency among clupeoid fishes is referred to be Lebour (1919), Bigelow (1926), and Shelbourne (1953) who agree that fish probably feed on those organisms that are most plentiful in the water. There is little doubt that this is the case in connection with copepods, and with young *Dascyllus albisella*, it might also apply to larvaceans which are abundant in their stomachs.

Other factors no doubt play a part in these relationships. It is reasonable to suppose that the vulnerability of the prey would be related to its size, structure and behavior as well as the efficiency of the predator. Shelbourne (1953) states that "the number and efficiency of sense organs, conspicuousness, special escape reactions, secretion of repellents, and the swarming habit are but a few of the factors which might well decide how far a particular prey is open to attack by a particular predator." He goes on to say that "with the concept of vulnerability in mind, it is easy to see why the soft-bodied, slow moving, but conspicuously vibratile *Oikopleura* (Larvacea) should fall a ready victim to a visual feeder."

The change in food habits of juvenile *Dascyllus albisella* appears to be a general pattern that is followed by other plankton feeders. In general, copepods are the major food of young fish, with greater numbers of other crustacea being consumed as they grow older. Bigelow (1926) wrote that larger herring in the Gulf of Maine took copepods and euphausiids while fish under four inches took chiefly copepods. Bigelow and Welsh (1925) add in reference to the same body of water that herring over 12 mm. depend exclusively on copepods for a time, and as they get larger they feed on larger prey, turning to the larger amphipods, shrimp and decapod crustacean larvae. Hildebrand and Schroeder

(1927) say that mysid shrimps appeared to be the principal food of adult anchovies (Anchoa mitchilli Cuvier and Valenciennes), while copepods were apparently the sole food of the young. In any of these species, the advantage is apparent of having adult fishes utilizing different food than the young. However, it might be even more important in connection with young Dascyllus albisella that will not move from a restricted area to obtain their food.

The influence of food on distribution was not studied in detail. Because of the mixing of reef water by currents and surge, it is presumed that the planktonic food organisms of Dascyllus albisella were uniformly distributed, although plankton tows to verify this were not made. A lack of local concentrations of plankters would remove an influence that might cause juvenile Dascyllus albisella to concentrate in their vicinity. In addition, the scarcity of empty stomachs suggests that food is almost always available. If fish congregated in places where food was plentiful, then one would expect to find large numbers of fish on shallow flats because of the greater flow of water that would bring more plankters to them. It was apparent that such large concentrations did not exist.

3.9 HYDROGRAPHIC FEATURES OF THE ENVIRONMENT

3.9.1 Characteristics of Current

An attempt was made to study surge velocities by the use of flow meters of the Rigosher type kindly loaned by the U. S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii. This equipment was modified by the addition of a large fin that kept the meter pointed into oncoming current or surge. The equipment was first used in the calmer portion of the Waikiki area and it was found that in spite of a very free-spinning set of blades, it would not always record. In other areas where current and surge were mild, the blades often would fail completely to respond. It became apparent that the rapid changes in direction and the short duration of most surges in the shallow reef area would necessitate the design of special equipment. This problem presents a magnitude of difficulty that has resulted in a lack of commercial gear designed for such studies. Therefore, this approach to measuring current and surge was abandoned.

An attempt was made to employ a drift bottle that was hydrostatically buoyed in such a fashion as to float just off the bottom. It was hoped that watching such a device would make it possible to measure the current close to the bottom where fish live. However, local turbulence close to the bottom tended to alter the hydrostatic balance of the bottle, thus causing it to rise or descend out of the area of interest.

The method finally adopted utilized naturally drifting particules in the water. The procedure was to locate a small particle of suspended matter and to watch the way in which it moved as an index to the motion of the water. If the observed particle settled to the bottom, other nearby particles were always available.

The observer carried a handful of 1 x 1 inch lead squares that were painted white. Since numbers were painted on them, they could be dropped when ever necessary to leave a consecutively numbered trail along the bottom. The distance between the squares was measured by means of a metal rod marked off in 6-inch lengths or a one-foot ruler depending on whether current or surge was being measured. The time it took particles to travel a measured distance was read from a watch sealed in a bottle. Time measurements were made independently of distance measurements because of difficulties inherent in doing two things simultaneously under the conditions encountered in the field. By combining time and distance measurements it was possible to determine velocities of currents and surge.

To measure current independently from surge was an extremely difficult task. The problems arose because of the complicated patterns of surge that are superimposed on a more or less steady current. A discussion of surge can be found in the section dealing with that subject; however, it is necessary to include a word about surge as it applies to current so that a definition of current as used here can be given.

There are two general types of surge. One is an alternating type that pulses toward shore and then immediately reverses to pulse in the opposite direction. This type of surge is of no concern here because such pulses were not included in current measurements. The other type of surge pulses in a shoreward direction only. This type is difficult to measure because a considerable amount of subjectivity is involved. A strong shoreward pulse can be recognized as such, but a gradation of intensities of pulses exists that makes it difficult to determine the onset or cessation of activity. Instruments could probably be designed to measure such one-way pulses, but this problem alone is quite formidible.

The current that was measured was the more or less steady flow of water in a given direction plus a component of one-way pulses of surge that were traveling in the same direction as the current on the incoming tide, but which were traveling against it on the outgoing tide. The resulting current velocities were therefore higher than they should have been on the incoming tide and possibly lower than they should have been on the outgoing tide.

In making measurements on a particular day, it was necessary to wait for a current change to take place so that both tides could be measured. Accordingly, measurements were made two hours before the change and two hours after the change. Measurements were made in one section of an area and then the observer immediately swam to the other section and repeated the measurements. This procedure was followed on both tides.

Figure 27 summarizes the current velocities that were measured at Kaneohe Bay, Kualua, and in the Waimanalo areas. Measurements were made at each place on two different days and at comparable stages of both the outgoing and the incoming tides. The data are meant only to show that differences exist between recognized rougher and calmer sections of the areas studied, as well as to give an idea as to the magnitude of current velocities on two days when wind and sea conditions appeared to be about average for the season. Measurements were made on different days in the different areas as it was not possible to cover all of the areas in one tidal cycle to make the measurements comparable. For this reason, it was decided that the valid comparisons that could be made were between tides and sections of reef within areas on a particular date.

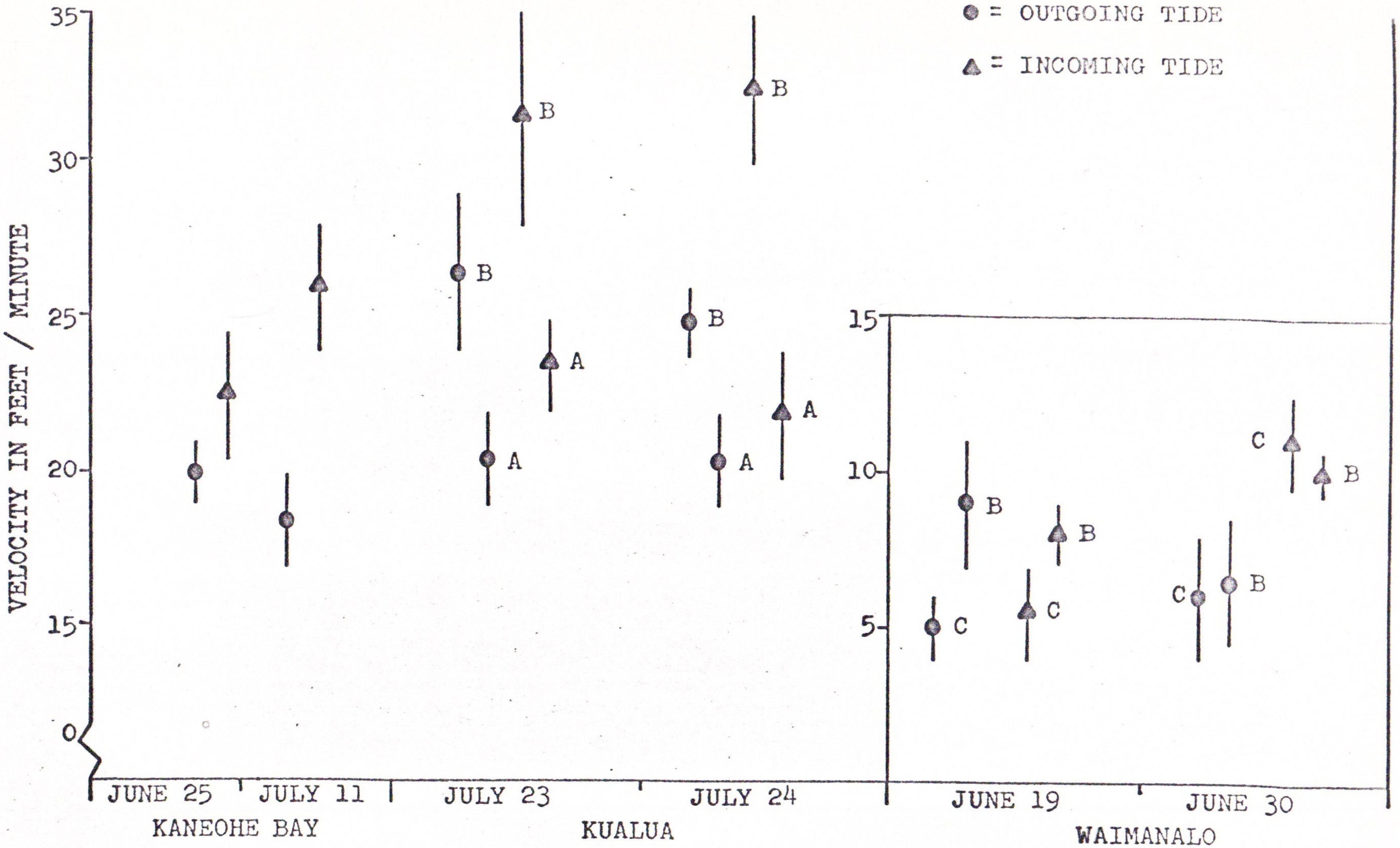

Figure 27. Average and ranges in current velocity observed in sections of three study areas during the summer of 1961.

The data in Figure 27 show that stronger currents occurred on the incoming tides. This was particularly noticeable at Kualua where the velocity of the current on the incoming tide averaged as much as 11 feet per minute faster than the outgoing tide in the surge zone, and as much as 6 feet per minute faster on the outgoing tides. On both of the days during which observations were made, the current had a greater velocity in section B.

Although the two measurements at a given spot during a given tide produced a rather wide range, it can be seen that the ranges for outgoing and incoming tides did not overlap to any extent except at Kualua on July 24. Therefore, a real difference appears to have existed on the days during which the observations were made.

The greater velocity in section B has a hydrographic as well as a topographic basis. The rather constant flow is caused partly by the incoming waves that follow each other in rapid succession, the result being what might be termed a "surge-related current." In addition to this, the outer edge of the reef in the surf zone rises to within 2 or 3 feet of the surface, thus causing a shallow barrier to the deeper reef flat toward shore. To fill the resulting inshore basin the water must flow over this barrier and the result would be a faster current. These two factors could thus be expected to function together in producing a stronger velocity on the incoming tide.

The currents in Kaneohe Bay appear to be less strong than in section B at Kualua and the variation between measurements is less. Although the measurements with the Kaneohe Bay and Kualua areas were made on different days, they are consistent with the strong impression one gets that the outer reef at Kualua is swept by much stronger currents as well as surge. This idea is also supported by the fact that the Kaneohe Bay area is considerably deeper than the outer flat areas at Kualua. Current velocities are greater at the surface than at the bottom -- particularly in deeper waters.

The currents at the Waimanalo area were much weaker than those in the other two areas. Section B had a pattern that was similar to Kaneohe Bay and Kualua with the stronger components appearing during the incoming tides. The ranges in the measurements, however, show more of a tendency to overlap than in the other areas. Section A had very little current which tended to flow in various directions. Although section C was deeper than B, the currents were comparable. It was noticed that currents close to the surface were much stronger than those near the bottom. This was particularly noticeable in the deep areas (C and D). Section D had a slight current that was apparently weaker than the other sections at Waimanalo.

In addition to having weaker currents than the other windward areas studied, it was observed that the currents present in section A and B flowed in a direction that almost paralleled the shore. Both of these differences are explainable on the basis of the proximity of the area to shore as well as to wave direction. In section A as well as the surrounding sections, waves tended to sweep at an angle to the shore which probably influenced current direction. In addition, the Waimanalo area is situated within 100 yards of the shore so that the tidal flow has very little distance to travel. The Kaneohe Bay and Kualua areas are located about half a mile or more from shore where the water is still traveling rapidly as it fills the inshore parts of the reef.

Currents in the Waikiki area were not measured. A slight current appeared in the surge zone and paralleled the shore somewhat as at Waimanalo. During times when other work was being carried out in the area, the velocity was estimated at less than 5 feet per minute and it was often hardly perceptable at all, as indicated by the pattern of distribution of markers that were being used to study surge. Currents offshore were rarely observed at all and were very slight when encountered in the study area. Heavier currents were sometimes noticed near the surface, but they were considerably reduced near the bottom.

3.9.2 Characteristics of Surge

Surge is defined here as an increase in the velocity of water over a short period of time which usually lasts from about 1 to 4 seconds. If an area is kept under observation for a time before measurements are made, it soon becomes apparent that water movements that fit the above description come predominantly from a direction corresponding to the direction from which the waves are traveling. Such increases may be of two types: 1) a surge from the direction of the approaching waves; 2) a back surge that travels in the opposite direction. In many cases, surges come in a series which cause the water to oscillate back and forth for about a minute. Such back and forth water movement seems to be caused by series of waves that are larger than others. In many instances, surges can be seen that travel only toward shore. They apparently result from waves that are smaller in height than those that cause alternating surges. Some of these surges are easy to detect while others are so weak or are of such short duration that they are difficult to identify. The shallow reef environment is characterized by moving water that predominantly flows in relation to waves and tides, but cross-currents, eddies and other turbulences are present.

The observations on surge were made in much the same way as were those on current. Numbered markers were laid down on the bottom at the limit of a particular surge just as the water began to move in the opposite direction. After a series of surges the distance between the tags (i.e., the distance of the surges) was measured in inches. Only those surges that alternated their directions were measured. Since one-way surges are difficult to measure, the first surge of a series that was measured was a back surge, or one that was traveling away from the shore. Correspondingly, the last surge measured in a series was also taken as a surge that was traveling away from shore. Such alternating surges almost always came in groups, or series, and appeared to be of a stronger nature than the one-way surges.

Time could not be measured simultaneously with the measurement of surge because of the joint tasks of dropping tags and keeping oriented in the water. Therefore, the individual surges of a series were timed using the same criterion of beginning the measurements with back surges.

Observations were made at Waimanalo on July 7, 8 and 9, 1961, during conditions of normal trade wind weather. Measurements were similarly made at Kualua on July 23 and 24, and in Kaneohe Bay on July 22 and 25. The incoming tide alone was measured at Waikiki on May 13 and 14. Each time and distance measurement was based on 25 surges.

An analysis of variance was carried out to determine whether or not the measurements made on the various days differed significantly. Since the differences were not significant, the days were combined to give a single average distance for surges within each section within each area. The average was divided by the average time for surges to give the average velocities shown in Figure 28.

3.9.3 Velocity of Surge

An examination of this figure shows in all instances that the average velocity of surges was greater during the incoming than the outgoing tides. It should be noted that only the incoming tide was measured for surge at Waikiki. The increase in velocity during flooding tides ranged from about 100 percent within section A at Waimanalo to about 300 percent within section D. It can be seen that the areas having the least surge were sections C and D at Waimanalo, which represent the deeper and quieter portions of the areas studied. Section A at Kualua, although not as deep as those mentioned above, represents the relatively sheltered inshore portions of the reef in that area. It can be seen that the velocity in the inshore section (A) was much less during both tides than that in the section (B) near the surf zone. The velocities in Kaneohe Bay differed considerably between the incoming and outgoing tides. Since this area had no rougher and calmer sections for comparison, the figures can only be taken as tidal differences for the area, which had

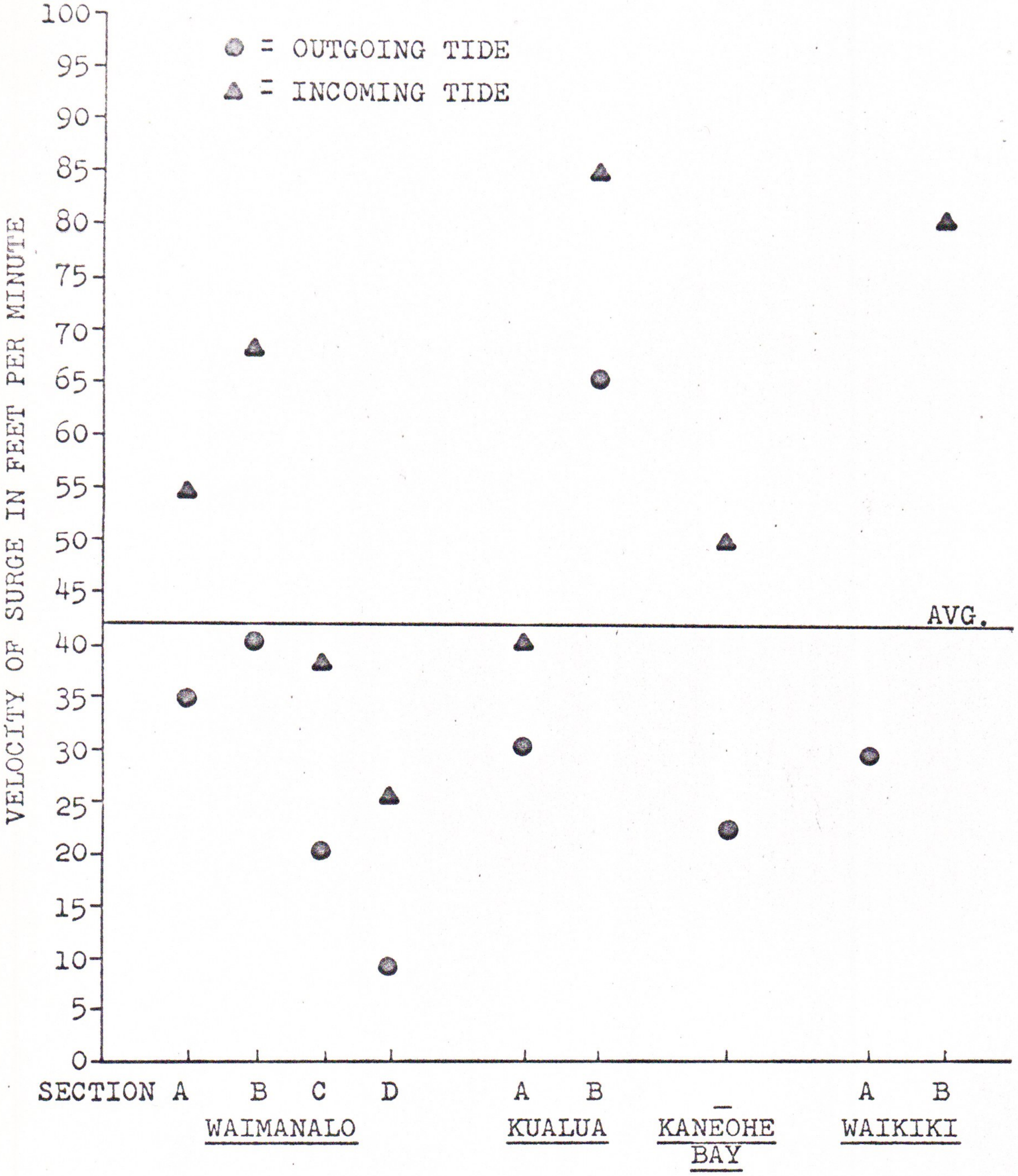

Figure 28. Average velocities of surges observed in study areas during incoming and outgoing tides in 1961.

less surge when compared with places like section B at Kualua. The deep offshore section (A) at Waikiki also showed velocities that averaged only about one-third of those found in the surge zone (section B). Although section A at Waikiki is an entirely different area from D at Waimanalo and was measured at different times, it is quite apparent from repeated contact with both areas that both their surge velocities were far lower than those found in other areas.

From the data presented here it is apparent that surge velocities in the rougher sections of the areas were continually stronger than in the calmer sections. The differences persisting during both incoming and outgoing tides were often two or three times greater in the rougher areas. It is most interesting that a section of relatively great surge velocity existed far inshore of the actual breaker zone where surge was the strongest. This section (B at Waimanalo) was the shallowest place in which surge was measured and illustrates the type of situation in which localized shallow areas are subjected to greater surge velocities than deeper areas. This idea was reinforced by viewing the reef from a high vantage point. It could be seen that actual breaker areas existed in various locations within the reef where the bottom closely approached the surface. Swimming in these areas left little doubt that surge zone conditions existed where the water was shallow. The bottom in such areas generally had a bare "swept-clean" appearance, that was characteristic of Hawaiian reef front surge zones and only fish adapted to living in swiftly moving water were found there. A gradation of surge intensities existed between such breaker areas and deeper areas where the bottom was little disturbed by the influence of surface waves. The four sections at Waimanalo represented such a gradation. As was shown in Section 3.2, numbers of juvenile *Dascyllus albisella* increased with increasing depth. Since surge decreased with depth, surge and numbers of fish were inversely correlated.

3.9.4 Frequency of Surge

After a number of observations, it became apparent that surge had another component. This was the frequency, or number of surges per minute, that occurred in a particular section or area. Some sections, such as D at Waimanalo, seemed to have a low frequency, while others such as B at Waimanalo seemed to have a high frequency. Suspended particles in the water were watched to determine the motion of the surges. The number of back and forth surges per minute were counted for five 1-minute periods and an average number per minute was determined. As in measuring surge velocities, the first and last shoreward surges of a series were not measured because of the subjectivity involved.

Figures 29 and 30 show the frequencies of surge as

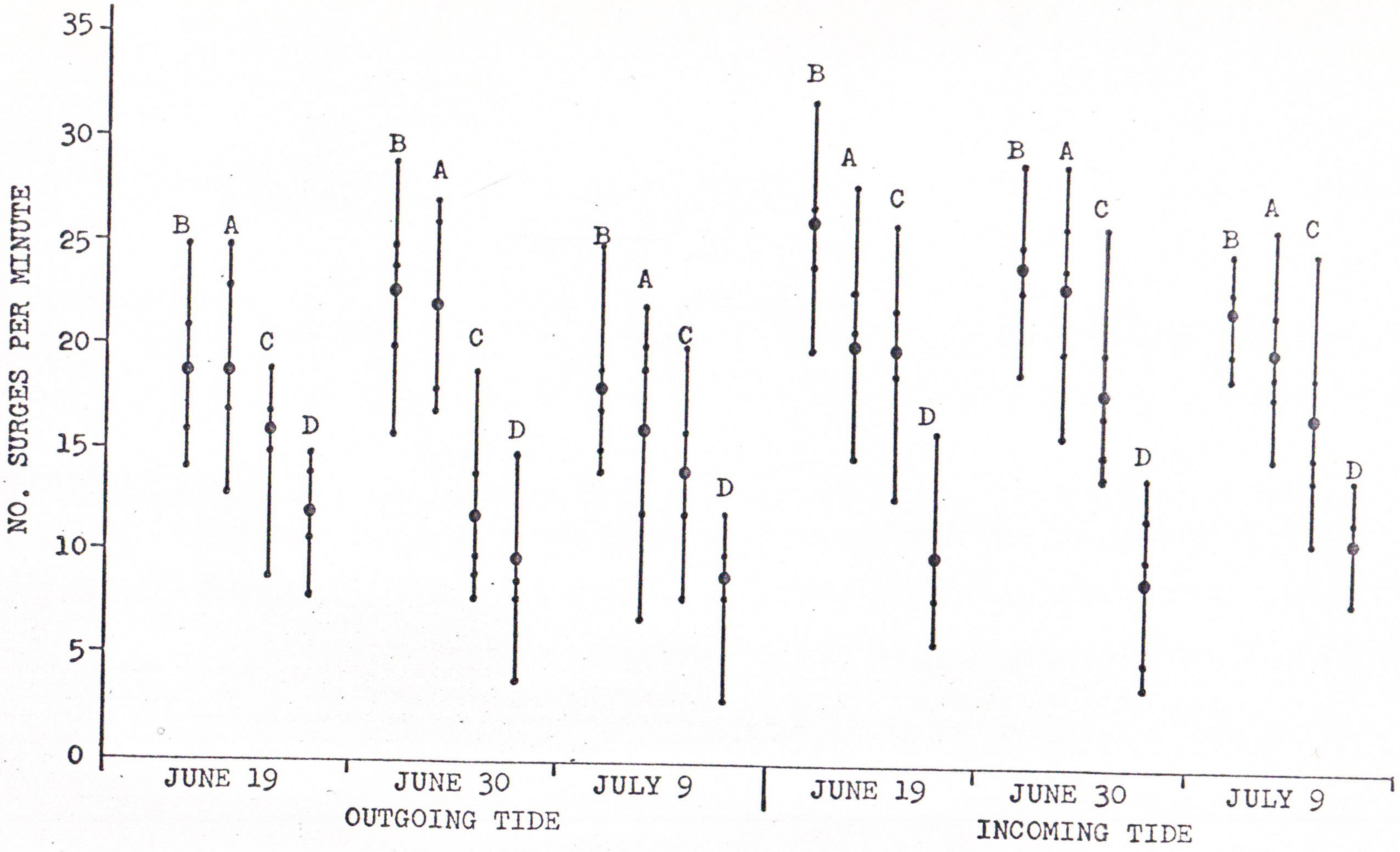

Figure 29. Number of surges per minute observed in the 4 sections of the Waimanalo study area during 1961.

measured in the different areas and sections on 7 different days. Individual measurements are indicated by the small dots on the straight lines that represent the ranges and the large dots represent the averages of a particular set of measurements. An examination of the data for the Waimanalo area for both incoming as well as outgoing tides shows a definite reduction in numbers of surges per minute from the roughest area (B) to the calmest area (D). To determine whether or not this trend was statistically significant, a contingency X^2 test was performed on the data. Although two different tides were involved, the data were all grouped together since the trend was very definite during both the incoming and the outgoing tides. The test showed that the hypothesis of independence, i.e., that frequency of surge was independent of area, was unacceptable ($P < 0.01$). Thus, it may be concluded that the shallower areas here were subjected to more alternating surges per minute than the deeper sections.

As surge in shallow waters seems to be definitely related to the action of waves, these results are readily explanable on the basis of the depth of the water. In shallow waters, the actions of more waves reaches the bottom and in deeper waters, only the stronger surges caused by the largest waves exert their influence on the bottom.

The outgoing and incoming tides on July 23, 1961, show little difference at Kualua. The data are so limited that it is not possible to make any statements about possible differences in numbers of surges per minute between sections A and B. The May 13 data for Waikiki indicate a possibly greater number of surges per minute in the surge zone (section B). Again, however, the data are too scant to allow a statement as to real differences that might exist between the sections. The number of surges in Kaneohe Bay were fewer on the outgoing than on the incoming tide, and like the Kualua and Waikiki areas, they were fewer than those on the shallow sections at Waimanalo (i.e., sections A and B).

It is possible that in the Kualua and Waikiki areas, the velocity of the surges might be the component of surge that affects the distribution of juvenile _Dascyllus_ _albisella_. However, at Waimanalo both velocity and frequency of surges might be instrumental in affecting distribution. In any event, there are many possible ways in which surge could affect fish that were exposed to its action. Whether fish are overtaxed by surges of certain velocities or frequencies, or whether some combination of factors occurs such as fish being thrown against coral heads by surge at night, is not known. On one occasion juvenile _Dascyllus_ _albisella_ were seen inside a coral head shortly after dawn at Kewalo Basin. However, it is not known whether or not juveniles enter coral heads at night in areas where there is surge.

The measurements of the velocity and frequency of surges were made during conditions of normal summer trade wind weather. The average wind velocities on the days during which the observations were made varied between 7.8 and 11.6 knots and the tides varied between -0.2 and +2.0 feet. Although these variations might have resulted in increased or decreased surge velocities, etc., such were not of sufficient magnitude to be apparent to the observer during frequent visits to the areas. Stronger winds increase the velocity of surges on reefs because surges are related to waves that are in turn related to the ocean waves that cause them. Stronger surge probably would drive juveniles off the shallower parts of the reefs, thus narrowing the pattern of distribution to include only the more protected shallow and deep areas. Conversely, periods of very reduced winds might allow aggregations to build up in areas where they would not be found under normal conditions. If such conditions coincided with periods during which large numbers of juveniles were coming into the reefs, distributions could be affected for a whole season.

3.10 SALINITY

Due to the effects of breaking waves, currents, surge, irregular bottom contours, etc., it was expected that little differences in salinity would be encountered in most of the areas studied because of the great amount of mixing. The deep water areas at Waikiki were not expected to vary since they are covered by ocean water that normally has a very constant salinity. However, a number of water samples taken at Waikiki and Waimanalo were tested to determine the salinity. The Waikiki area received the most attention since observations were made in connection with the study of reproduction.

Samples at Waikiki were taken within two feet of the bottom by opening an empty bottle at that depth. The first filling was flushed out by inserting a tube and filling it with compressed air. The bottle was then refilled and stoppered underwater before it was brought to the surface. The temperature was recorded at the same time that the water sample was taken.

Samples were taken in the same way at Waimanalo along with temperature readings. Salinities throughout the water column were determined from a series of samples taken from the top and bottom of the water column in both the deep and shallow sections of Waimanalo. The resulting comparison was expected to give an idea of the completeness of mixing based on the degree of uniformity of the salinities and temperatures.

Salinities were determined from the water samples by the conductivity method, the the work was carried out by the Honolulu Biological Laboratory of the United States Fish and Wildlife Service.

Figure 31 shows that there was very little variation in the bottom salinities at Waikiki in 1960. Although no determinations were made in the inshore surge zone area, there is no reason to suppose that bottom salinities would vary from the locality tested.

The three determinations made at Waimanalo in 1960 show a variation of only 0.07 parts per thousand between the deep and shallow areas, indicating the rather complete mixing of the water mass. On August 16, 1961, four samples were taken to determine whether or not differences existed between the upper and lower parts of the water column. The greatest variation, which occurred in section A, was only 0.03 parts per thousand between the top and bottom of the water column which were separated by about four feet. These results again show the uniform salinity conditions in the area.

3.11 TEMPERATURE

Temperatures were measured to tenths of a degree using an ordinary centigrade thermometer, and were recorded on a

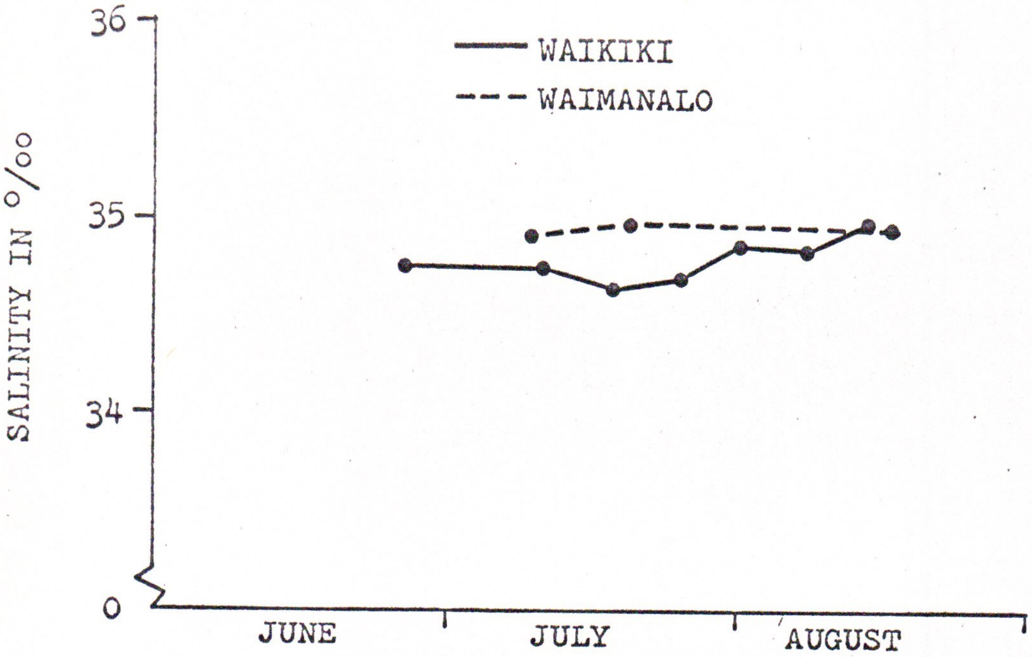

Figure 31. Average salinities in the Waikiki and Waimanalo study areas during summer of 1960.

plastic sheet while underwater. As with salinities, the recordings were made close to the bottom where the fish live. When salinities were taken the temperature was also recorded.

Figure 32 shows the temperatures recorded from both the Waikiki and Waimanalo areas. The temperatures at Waikiki in 1960 show a very gradual rise throughout the summer and a gradual decrease during early winter. Changes over a number of days are in the order of tenths of degrees rather than in whole degrees. As with salinities, the differences in temperatures between offshore study areas were slight with the greatest differences being only 0.2 degrees.

Bottom temperatures observed at Waimanalo during 1961 were for the most part rather uniform between the shallow flats of sections A and B and the deeper waters of section D. The three comparisons made during July and the one on August 18 show somewhat more fluctuation, although the variations were still of the order of magnitude of tenths of one degree. The figures indicate that the temperatures at section A were higher in late summer than in early summer.

3.12 FIELD EXPERIMENTS WITH AGGREGATIONS OF FISH

Experiments were carried out in which fish and coral

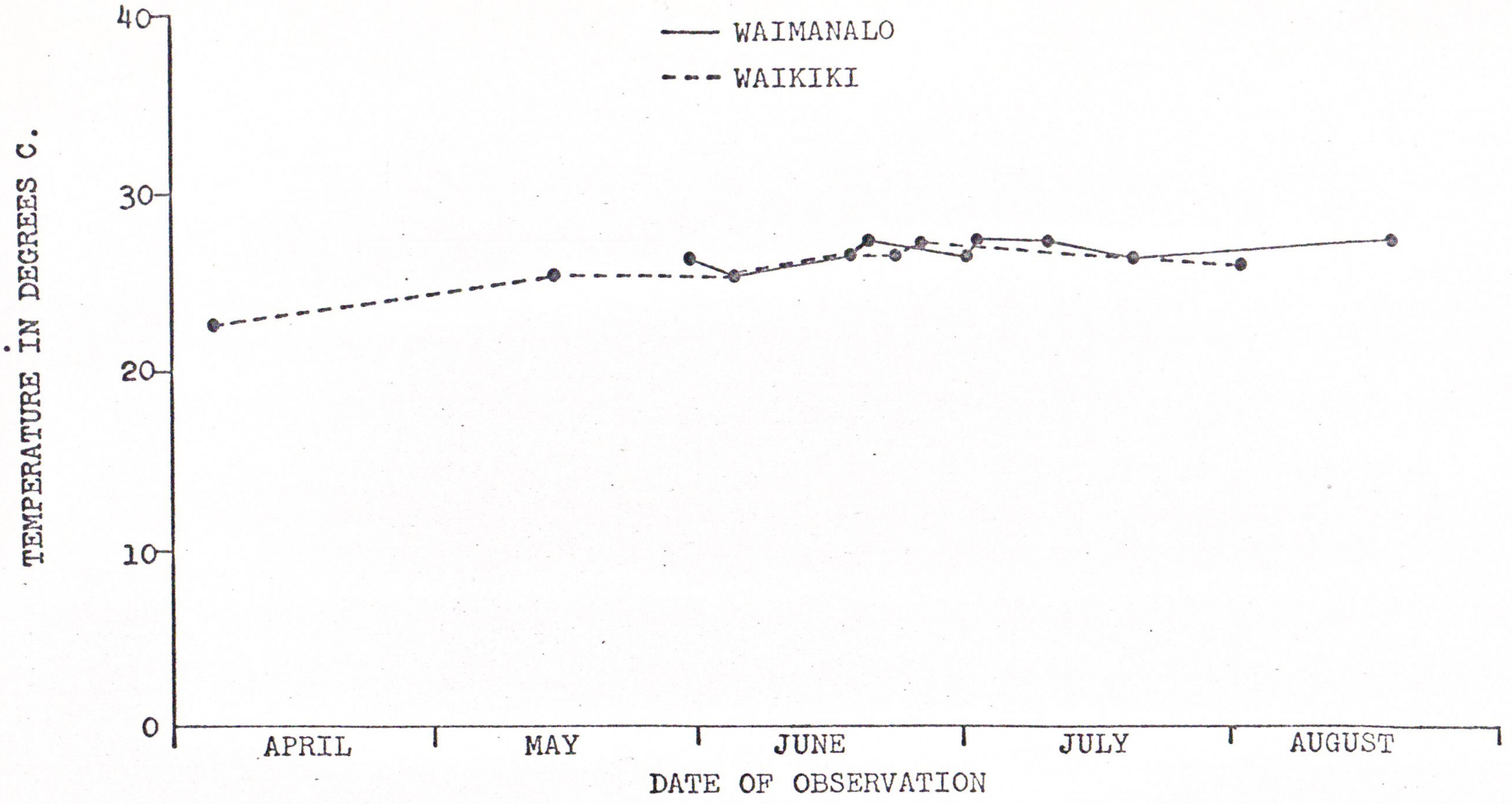

Figure 32. Average temperatures observed in the summer of 1961 at Waimanalo and in the spring and summer at Waikiki.

heads were transplanted in the field to areas that appeared to represent both suitable and relatively unsuitable habitats for juvenile Dascyllus albisella. It was hoped that observation of these aggregations would give additional information concerning the increase and decrease of numbers of fish in such areas. The areas chosen for this work were sections B and D at Waimanalo and section A in the offshore area of Waikiki. The main reason for choosing the latter area was to determine whether or not the presence of coral heads, which were naturally absent, would attract juvenile fish.

Coral heads were transplanted to the study areas and were made fast to the bottom by wiring them to boards that were mounted on iron stakes driven into the bottom. In this way, the head became situated in a more or less natural position close to the bottom in such a way that wave action could not sweep it away. Juvenile Dascyllus albisella were captured and introduced into the coral heads after they were placed on the bottom.

3.12.1 Experiments at Waikiki

Since few live ramose coral heads were available in the Waikiki study area, they had to be brought from the surge zone area close to shore. Pocillopora meandrina coral heads were common in the area and were used in this study.

Four live coral heads were placed over rock bottom

(9, 10, 11 and 12 - Figure 33), and four live heads were placed over sandy bottom (1, 2, 3 and 4). In addition, four dead coral heads were placed over rock bottom (13, 14, 15 and 16), and four were placed over sandy bottom (5, 6, 7 and 8). The dead coral heads were the same species as the live ones and, judging from the amount of algae growing in the interstices, had been dead for some time.

Because of the difficult working conditions, fish could not be introduced to all of the coral heads at the same time. On June 11, five fish each were introduced in heads 1, 2, and 9, 10, which consisted of two live heads over rock bottom and two live heads over sand. On June 15, heads 3, 4, and 11, 12, and 13, 14, 15, 16 received five fish each, which were comprised of two more live heads over sand, two more live heads over rock bottom and four dead coral heads over rock bottom. Head 5 was a dead coral head that was placed over the sand on June 15 without any fish and was found to have a natural aggregation when examined on June 22. On that day, three more dead coral heads were placed on the sand and five juvenile Dascyllus albisella were introduced into each.

The first twenty fish introduced into heads 1, 2, 9 and 10 on June 11 were obtained from sea urchins in the area. However, since sea urchins and associated aggregations of fish were kept under observation from that date (Section

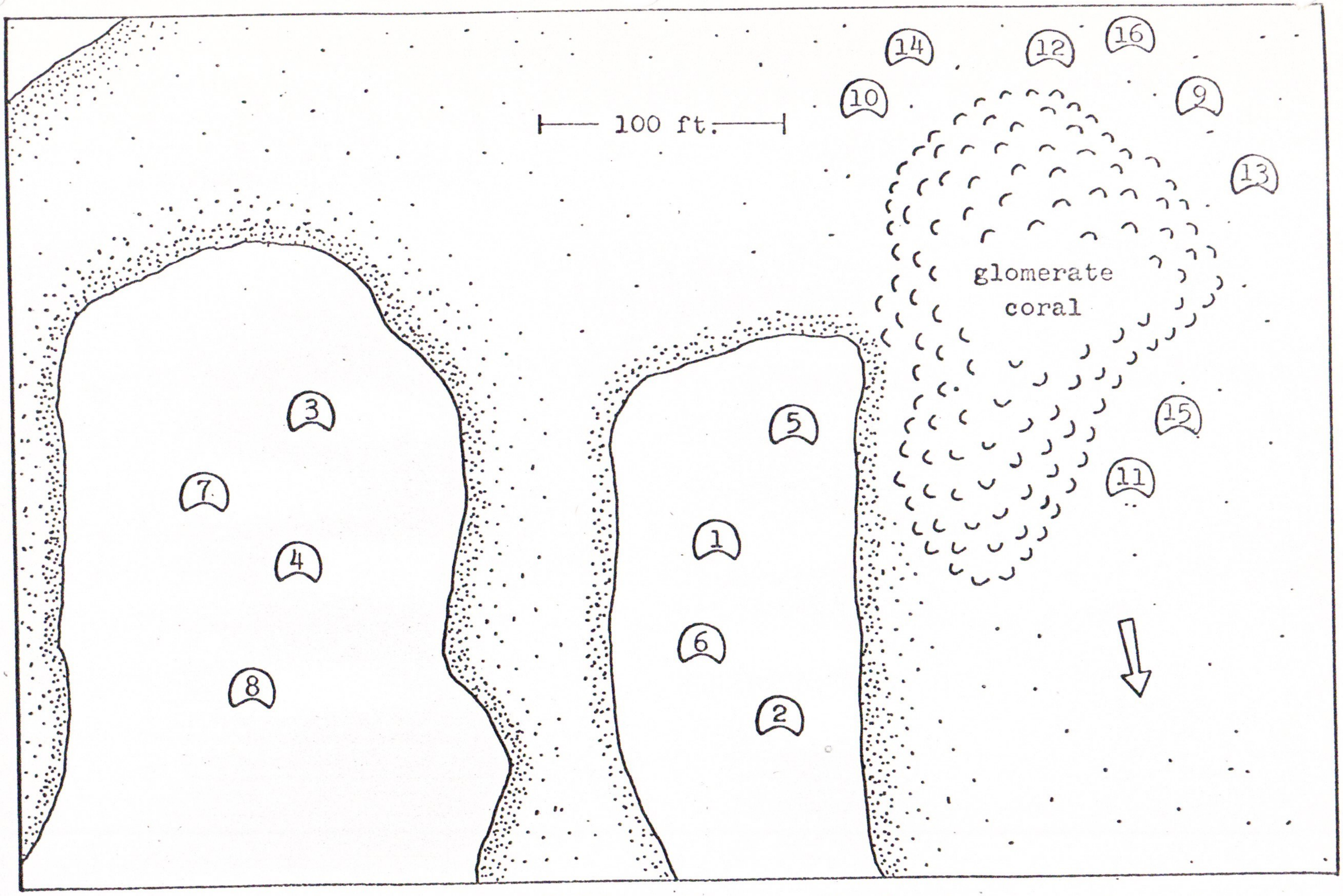

Figure 33. Map of section A, Waikiki study area, showing location of coral heads and other geographic features.

3.13), no more fish were obtained from that source. Fish introduced into the remaining 11 coral heads were obtained from a general area off the town of Waimanalo. These fish were captured the day before introduction into the field and were slowly brought to the same temperature as the sea water before release.

Figure 34 shows the resulting increases and decreases in the numbers of fish in the experimental coral heads transplanted at Waikiki. The histograms topped by a bar represent estimates of the abundance of fish present since numbers were so great as to prevent accurate counts (which could be made up to about 30 fish). The extreme right-hand histogram in each set of observations represents the final observation of July 30. Fish were captured at that time and were brought back to the laboratory for measurement.

The large build-up in numbers in the live coral heads on the sand is evident (Figure 34 - 1, 2, 3 and 4). The numbers of fish were so great that all the interstices between the branches of the coral were filled when they retreated into the coral heads. Although these heads were only about 8 to 10 inches in diameter, there was still room for the fish to retreat deep enough within so that they were not exposed beyond the periphery of the head. The dead coral heads on the sand (5, 6, 7, 8) also contained large concentrations of fish although the quantities were

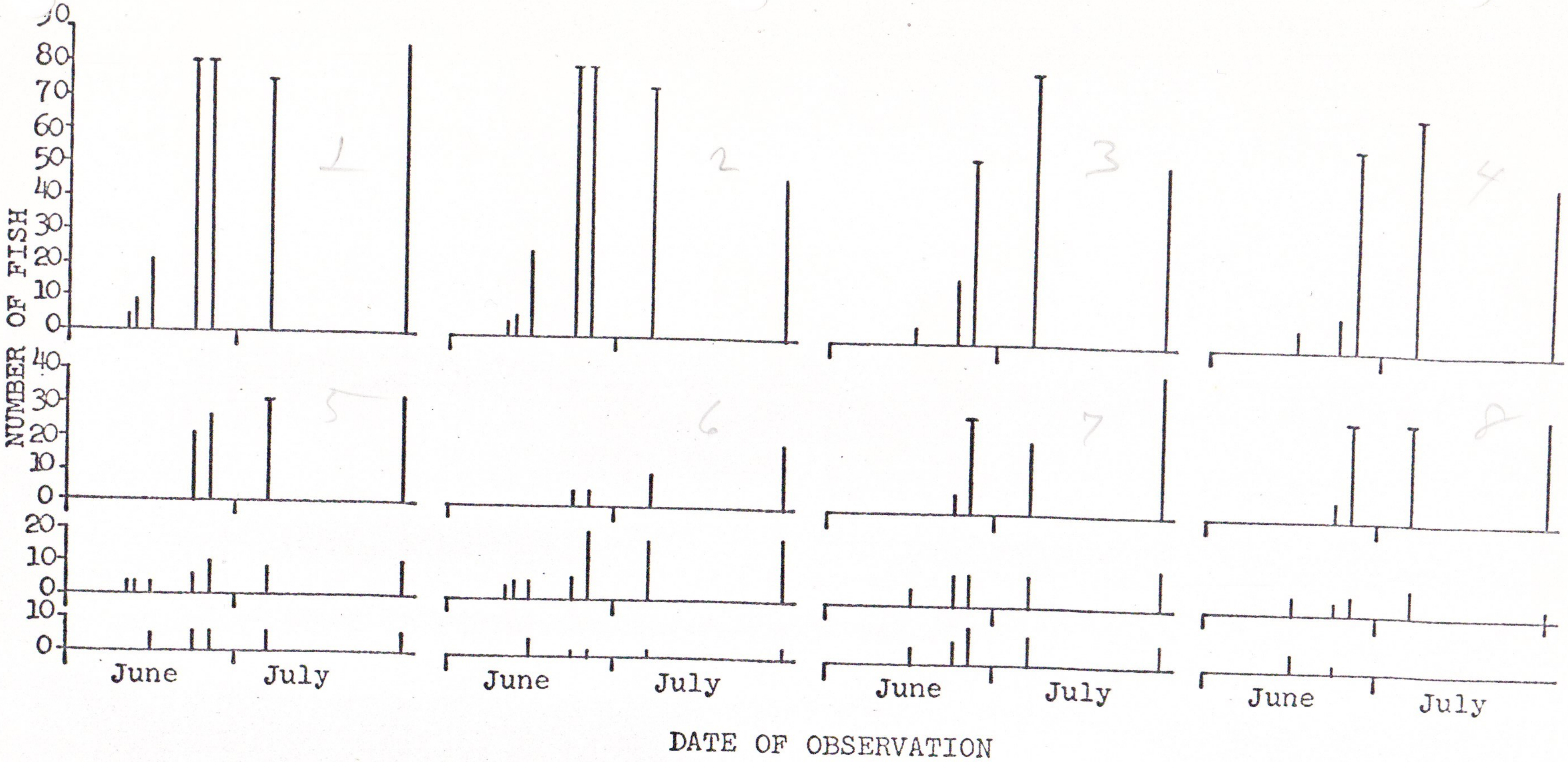

Figure 34. Observations of numbers of fish colonizing experimental coral heads at Waikiki in summer of 1961.

considerably less than in the live heads. Numbers of fish in live heads that were placed over the rock bottom (9, 10, 11, 12) tended to increase slightly although the numbers in head 10 tripled. In only one instance did the four dead coral heads over hard bottom (13, 14, 15, 16) increase in numbers of fish and this increase was slightly less than double the original number placed there. In two instances, the introduced aggregations were reduced while the remaining coral head contained the same number of fish that was introduced. Figure 10, taken off Waikiki at a depth of 70 feet in the study area, shows experimental coral head #9 over the rock bottom and Figure 11 shows head #1 over the sand. The greater number of fish in the head over sand is evident.

The large numbers of fish in the live heads on sand make it difficult to gain information concerning the mechanics of recruitment. Heads 1 and 2 showed a great increase in numbers of fish between June 15 and 22, while heads 3 and 4 showed similar increases between June 22 and 25. If these increases were part of the same influx of new fish, then it is reasonable to assume that the increase might have occurred sometime around June 22. With one exception, it appears from these data that only one large increase in numbers of fish occurred. However, head #7 gives an indication that another increase occurred between July 5 and 30.

Figure 35 shows the length frequency distributions of